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<http://dx.doi.org/doi:10.21954/ou.ro.0000866f>

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**ANALOGICAL REASONING IN CHILDREN'S
READING AND ADDITION**

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Thesis submitted for the degree of Doctor of Philosophy

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August, 2004

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Submission date: 31 August 2004
Award date: 17 January 2005

ABSTRACT

The purpose of the research was to examine the role of analogical reasoning in children's early reading and addition and to look for possible commonalities in children's performance across these two educational contexts. The research comprised four studies. Study 1 was a preliminary investigation of individual differences in children's use of analogies in beginning reading. In this study, 55 five-to six year-old beginning readers were presented with the traditional clue word analogy task incorporating either real word or non-word test items. After the presentation of an initial clue word that was decoded for them, children were asked to read a series of related and unrelated target words. Distinct patterns of analogy emerged with regard to the children's ability to use different combinations of orthographic and phonological relations using cluster analysis. The findings illustrated the usefulness of identifying profiles of orthographic and phonological relations for characterising children's development in learning to read. Study 2 was designed to extend the findings from Study 1 by examining whether children's traditional analogical reasoning abilities, short-term memory and their reading related skills could provide some explanations for these patterns of individual differences in reasoning skills in beginning reading. The results of Study 2 supported those of Study 1 revealing distinct patterns in children's use of orthographic and phonological relations. Although single word reading and early phonological knowledge were systematically related to these different patterns of analogy, measures of traditional analogical reasoning skill were unable to account for differences in children's profiles. The purpose of Study 3 was to systematically explore the possibility that analogies are important for children's addition. In this study, 66 five-to-seven year-olds were given an addition-based analogy task designed to assess their ability to solve series of addition problems that were either conceptually related or unrelated to a solved addition problem. Similar to Study 2, children also solved a series of traditional analogical reasoning tasks,

designed to assess their ability to solve analogies based on thematic, causal and visual relations. The results indicated that children's use of analogy to solve commuted addition problems was systematically related to their profiles of addition problem solving skills, although no relation was found between children's use of addition analogy and traditional analogical reasoning tasks. In Study 4, 69 five-to-six year-olds were given a revised version of the reading and addition analogy tasks presented in Studies 2 and 3 to examine possible similarities in children's analogical reasoning skills across the two domains. Individual self-reports of strategies showed that the children relied on a wide repertoire of strategies for solving related analogy problems in reading and addition. Furthermore, children's patterns of responses to solving analogical problems indicated that most children who reported using analogy strategies in early reading had high levels of analogical reasoning in addition. The findings suggest that there may be a common analogical reasoning component underlying the two domains of reading and mathematics. Overall, the four studies suggest that children's ability to reason about conceptual relations are an important aspect of their development in reading and addition and that the study of analogical reasoning across different educational contexts can provide important insights into children's cognitive development.

DECLARATION

This thesis comprises my own original work and due acknowledgement has been made to all material used within this thesis where appropriate. Financial support was provided by a research studentship from the Economic and Social Research Council. The thesis comprises less than 100,000 words (inclusive of tables, references, and appendices).

A paper based on Study 2, in Chapter 6 has been published (Farrington-Flint, L., Wood, C., Canobi, K. H., & Faulkner, D. 2004. Patterns of analogical reasoning among beginning readers. *Journal of Research in Reading*, 26, 226-247).

Lee Brian Farrington-Flint

ACKNOWLEDGEMENTS

The most important acknowledgement is to my supervisors, Clare Wood, Dorothy Faulkner and Katherine Canobi whose support, encouragement, and guidance has been invaluable. This thesis is the result of their continuous support and commitment.

I would like to thank all of the staff and pupils at the participating schools who kindly agreed to participate in this doctoral research. They willingly gave up their valuable time and energy to make this research possible, which is greatly appreciated. I would also like to thank my family and friends for their continuous help and support during my doctoral studies, especially Mum, Nana, Anna, Lisa, David, Deborah and Craig. I also thank my fellow students, especially Gareth, Becky, Carina, Rob, Rachel, Eileen and Jenny who offered useful advice and made the PhD process such an enjoyable experience. I am also particularly grateful to Gareth for his efforts in designing the computer software programs that were used in the current research program.

I would also like to thank my colleagues in the Centre for Childhood, Development and Learning (ChDL), for their support, guidance and advice throughout the three years and members of the Department of Psychology at the University of Melbourne for sharing their knowledge and expertise with me during my visit to the department in 2004.

DEDICATION

This thesis is dedicated to the memory of my grandparents,
Bernard and Eva Farrington for their continuous love, support
and guidance over the years and helping me to understand
the important things in life. Thank You.

CONTENTS PAGE

CHAPTER ONE

THE DEVELOPMENT OF CHILDREN'S ANALOGICAL REASONING

1. Introduction	1
1.1. Developmental Approaches to Analogical Reasoning	3
1.1.1. Piaget's Structural Theory of Analogy	3
1.1.2. Gentner's Structure Mapping Theory of Analogy	12
1.1.3. A Knowledge-Based View of Analogy	17
1.2. Analogical Reasoning in Specific Domains	21
1.2.1. Similarities in Analogy Skills across Domains	21
1.2.2. Contribution of Traditional Reasoning Skills	25
1.3. Chapter Summary	27

CHAPTER TWO

ANALOGICAL REASONING IN CHILDREN'S READING

2. Introduction	30
2.1. Domain Knowledge in Reading	31
2.1.1. Phonological Units in Reading	31
2.1.2. The Development of Phonological Skills	33
2.2. Analogies in the Context of Reading	36
2.2.1. Theoretical Models of Rhyme and Analogy	37
2.2.2. Experimental Studies of Reading by Analogy	40
2.3. Individual Differences in Analogical Reasoning	47
2.3.1. Age Related Changes in Analogy	48
2.3.2. Variability in Children's Strategy Choices	54
2.4. Chapter Summary	57

CHAPTER THREE

ANALOGICAL REASONING IN CHILDREN'S ADDITION

3. Introduction	60
3.1. Domain Knowledge in Addition	61
3.1.1. Knowledge of Formal Addition Principles	61
3.1.2. Developmental Progression of Addition Principles	63
3.2. Measuring Analogical Skills in Addition	67
3.2.1. Methodological Critique of Judgment Tasks	68
3.2.2. Methodological Critique of Problem Solving Tasks	69
3.2.3. Developing a Suitable Analogy Framework	72
3.3. Analogical Reasoning and Addition Problem Solving	75
3.3.1. Conceptual Understanding and Problem Solving	76
3.3.2. Patterns of Problem Solving Skills	83
3.4. Chapter Summary	86

CHAPTER FOUR

RESEARCH AGENDA

4. Introduction	88
4.1. Patterns of Analogy in Reading	89
4.2. Analogies in Addition and their Relation to Problem Solving	90
4.3. The Contribution of Traditional Analogical Reasoning Skills	92
4.4. Children's Consistency in Using Analogies	93
4.5. Individual Differences in Analogy Skills across Domains	95
4.6. Chapter Summary	96

CHAPTER FIVE

STUDY 1: PATTERNS OF ANALOGY IN BEGINNING READING

5. Introduction	98
5.1. Method	101
5.1.1. Participants	101
5.1.2. Initial Pre-Test and Screening	104
5.1.3. Materials	104
5.1.4. General Procedure	107
5.2. Results	107

5.2.1. Analogies in Reading	107
5.2.2. Patterns of Analogy in Beginning Reading	111
5.2.3. Explaining Patterns of Analogy In Reading	114
5.3. Discussion	117

CHAPTER SIX

STUDY 2: EXPLAINING PATTERNS OF ANALOGY IN BEGINNING READING

6. Introduction	123
6.1. Method	126
6.1.1. Participants	126
6.1.2. Initial Pre-test and Screening	127
6.1.3. Materials	127
6.1.4. General Procedure	132
6.2. Results	133
6.2.1. Analogies in Reading	133
6.2.2. Concurrent Prediction of Reading Analogy	137
6.2.3. Patterns of Analogy in Beginning Reading	142
6.2.4. Analogies in Reading and Traditional Reasoning Skills	145
6.3. Discussion	148

CHAPTER SEVEN

STUDY 3: ANALOGICAL REASONING IN CHILDREN'S ADDITION

7. Introduction	157
7.1. Method	161
7.1.1. Participants	161
7.1.2. Initial Pre-Test and Screening	161
7.1.3. Materials	162
7.1.4. Coding Self-Reports	166
7.1.5. General Procedure	167
7.2. Results	167
7.2.1. Analogies in Addition	167
7.2.2. Patterns of Problem Solving, Addition Analogies and Age	173
7.2.3. Analogies in Addition and Traditional Reasoning Skills	180
7.3. Discussion	182

CHAPTER EIGHT

STUDY 4: COMPARING CHILDREN'S USE OF ANALOGY IN READING AND ADDITION

8. Introduction	188
8.1. Method	191
8.1.1. Participants	191
8.1.2. Initial Pre-test and Screening	192
8.1.3. Materials	192
8.1.4. Coding	196
8.1.5. General Procedure	197
8.2. Results	198
8.2.1. Analogies in Reading	198
8.2.2. Analogies in Addition	203
8.2.3. Analogical Reasoning across Domains	204
8.2.4. Patterns of Strategy Choices across Domains	207
8.2.5. Explaining Patterns of Strategy Choice	211
8.3. Discussion	214

CHAPTER NINE

CONCLUSIONS AND IMPLICATIONS

9. Introduction	221
9.1. Review of the Research Findings	222
9.1.1. Patterns of Analogy in Beginning Reading	222
9.1.2. Analogies in Addition and their Relation to Problem Solving	226
9.1.3. The Contribution of Traditional Analogical Reasoning Skills	228
9.1.4. Consistency in Children's Strategy Choices	232
9.1.5. Patterns of Analogy across Domains	234
9.2. Implications of the Present Findings	237
9.2.1. Theoretical Implications	237
9.2.2. Methodological Implications	244
9.2.3. Educational and Practical Implications	246
9.3. Directions for Future Research	249
9.3.1. Individual Differences in Beginning Reading	249
9.3.2. Analogical Reasoning across Educational Domains	252

9.3.3. Educational Implications of Analogy Teaching	255
9.4. Conclusions	258
REFERENCES	260
Appendix A.	
Real Word Problems used in the Reading Analogy Task in Study 1	285
Appendix B.	
Non-Word Problems used in the Reading Analogy Task in Study 1	287
Appendix C.	
Non-Word Problems used in the Reading Analogy Task in Study 2	288
Appendix D.	
Addition Problems used in the Addition Analogy Task in Study 3	290
Appendix E.	
Non-Word Problems used in the Reading Analogy Task in Study 4	291
Appendix F.	
Addition Problems used in the Addition Analogy Task in Study 4	292
Appendix G.	
Examples of the Traditional Reasoning Tasks used in Studies 2 and 3	293

LIST OF TABLES

Table 5.1	Means (and standard deviations) for age, vocabulary and single word reading according to type of reading analogy task.
Table 5.2	Means, standard deviation and Cronbach's alpha reliability scores for children's accuracy in the different conditions for the real word and non-word tasks.
Table 5.3	Means (and standard deviations) of children's accuracy scores on the reading analogy task as a function of cluster.
Table 5.4	Means (and standard deviations) for age and pre-existing domain knowledge scores as a function of reading cluster.
Table 6.1	Means (and standard deviations) for the speed and accuracy of children's scores on the reading analogy task and the traditional analogical reasoning tasks.
Table 6.2	Correlations between reading analogy skills, phonological skills and traditional analogical reasoning skills.
Table 6.3	Fixed order regression analyses with composite orthographic and phonological analogy scores as the dependent variable and age, pre-existing domain knowledge and traditional analogical reasoning scores as predictors.
Table 6.4	Means (and standard deviations) of composite orthographic and phonological accuracy scores and solution times as a function of analogy cluster.
Table 6.5	Means (and standard deviations) for children's traditional analogical reasoning skills and their pre-existing domain knowledge as a function of analogy cluster
Table 7.1	Mean accuracy, solution time (and standard deviations) for problems in the addition analogy task.

Table 7.2	Means (and Standard Deviations) for individual children’s percentage strategy use, percentage of children who used particular strategies at least once and mean solution times (in seconds) associated with each strategy for correctly solved related problems.
Table 7.3	Means (and Standard Deviations) for individual children’s percentage strategy use, percentage of children who used particular strategies at least once and mean solution times (in seconds) associated with each strategy for correctly solved unrelated problems.
Table 7.4	Means (and standard deviations) for the accuracy, speed and frequency of self-report procedures as a function of problem solving cluster.
Table 7.5	Means (and standard deviations) of children’s age and their reported use of commutativity as a function of problem solving cluster.
Table 7.6	Fixed order regression with reported commutativity score as the dependent variable and traditional analogical reasoning scores as predictors.
Table 8.1	Means (and standard deviations) for the accuracy and speed of children’s performance on each condition in the reading and addition analogy tasks.
Table 8.2	Means (and Standard Deviations) for individual children’s percentage strategy use, percentage of children who used particular strategies at least once and mean solution times (in seconds) associated with each strategy for correctly solved related problems.
Table 8.3	Fixed order regression with age, pre-existing domain knowledge and self-reports of analogy in addition as predictors.
Table 8.4	Fixed order regression with age, pre-existing domain knowledge and self-reports of analogy in reading as predictors.
Table 8.5	Means (and standard deviations) for the accuracy of reported strategies in the reading and addition tasks as a function of cluster.
Table 8.6	Means (and standard deviations) for children’s age and their pre-existing domain knowledge as a function of cluster.

CHAPTER ONE

THE DEVELOPMENT OF CHILDREN'S ANALOGICAL REASONING

1. Introduction

Many psychologists interested in children's cognition agree that the development of analogical reasoning makes a key contribution to other areas of intellectual growth (Brown, 1989; Carey & Spelke, 1994; Goswami, 1992, 1996; Halford, 1992; Wellman & Gelman, 1998; Wellman & Inagaki, 1997). The ability to reason analogically involves the ability to make judgments or predictions about unfamiliar problems on the basis of perceived similarities and relationships with familiar problems. This form of inferential reasoning also serves a variety of different functions ranging from drawing children's attention to already known relations to the reorganisation and development of existing knowledge (DeLoache, Miller, & Pierroutsakos, 1998).

Given that analogical reasoning appears to play an important role in young children's learning, reasoning and knowledge acquisition (Goswami, 1996; Halford, 1992), it is likely that this form of reasoning ability will have particular importance in children's educational attainment. It is already established that analogies have potential value as a creative tool, allowing the child to recognise and learn similarities across a range of different situations, contexts or domains (see Wellman & Gelman, 1998). However, despite their utility for learning, and their importance for cognitive development, the different ways in which analogical reasoning skills may contribute to children's educational knowledge is an area that requires further consideration.

A central argument underlying this thesis, therefore, is the need to explore the use of analogical reasoning both within specific domains and across different educational

contexts. A more detailed consideration of children's application of analogical reasoning within specific educational domains and how this use of analogical reasoning relates to their general cognitive development is required. Theories of child development have frequently assumed that as a child grows, cognitive developments occur across domains (e.g. Inhelder & Piaget, 1958; Piaget *et al.*, 1977). However, accepting that there are global, domain-general shifts in children's development is problematic because such an approach appears to ignore individual differences in children's abilities (Siegler, 1996). In light of such claims, this thesis considers the use of analogical reasoning within two specific domains of knowledge, namely, the domains of reading and mathematics. It is argued that a more detailed examination of individual differences in children's analogical reasoning is required and further insight into the possible links or commonalities in the way in which children use analogical reasoning strategies across the two domains together is needed. It is also argued that further research is needed which focuses on the identification of the different strategies that children use when solving both reading and addition-based analogical reasoning tasks. These issues are central to the current research and are discussed in Chapters 2 and 3.

There is considerable evidence to support the claim that the ability to reason analogically is fundamental to children's ability to communicate, explore and transfer ideas, and is therefore, instrumental to children's cognitive development (DeLoache *et al.*, 1998). However, as illustrated in this chapter, the current conceptions of analogical reasoning within the developmental literature are both inconsistent and controversial. Beyond the most basic definitions, there are debates concerning what the term analogical reasoning entails and whether young children are capable of reasoning by analogy (see Goswami, 1992, 1996). The purpose of this chapter is to introduce the developmental literature concerning analogical reasoning and to discuss the development of reasoning skills in early childhood. Some of the key theoretical approaches to the

development of analogical reasoning will be discussed and the theoretical issues relevant to each approach will be reviewed. In the remaining sections of this chapter, the possibility of examining analogical reasoning within different domains will be introduced. It is claimed that examining the different ways in which young children use analogies both within and across different educational contexts will offer a useful contribution to the current analogical reasoning literature.

1.1. Developmental Approaches to Analogical Reasoning

It is important to begin by considering the different developmental approaches to the study of analogical reasoning and briefly address some of the most influential theories of analogy development. It will be argued that whilst earlier structuralist theories of analogical reasoning tended to assume that young children cannot reason about relations until the stage of formal operations (Piaget, Montangero, & Billeter, 1977), these claims are based on the findings from studies which failed to pre-test for children's existing knowledge of those relations. The finding that young children cannot reason about relational similarity may, therefore, be an artefact of using unfamiliar relations and failing to establish whether young children have the appropriate pre-existing domain knowledge. Given such limitations, it will be argued below that a 'knowledge-based' approach to analogical reasoning provides the most compelling characterisation of young children's reasoning capabilities.

1.1.1. Piaget's Structural Theory of Analogy

The theoretical work of Piaget (e.g. Inhelder & Piaget, 1958; Piaget *et al.*, 1977) has played an influential role in developing our current understanding of analogical reasoning in children. Indeed, the earlier theoretical literature on analogical reasoning was dominated by the Piagetian tradition. In his early work, Piaget claimed that analogical

reasoning, being a developmentally sophisticated skill, did not occur until the stage of formal operational thinking. Evidence that supports the notion that analogical reasoning skills are typically late developing comes from studies that used the classic pictorial analogy tasks. In his initial experiments, Piaget and colleagues (1977) examined children's ability to form analogies of the traditional form A:B::C:D (e.g., 'automobile is to gas as sailboat is to (travel/wind/sails/rudder)'). Pictures were used to assess relational understanding to ensure that possible constraints relating to vocabulary did not confound the results. Children, between the ages of 5 and 12-years, were first required to pair together a selection of picture cards that they thought were related in some way. The ability to correctly link the individual terms on both sides of the analogy (A and B or C and D), according to Piaget, demonstrated the child's understanding of lower order relations. Children were found to pair up pictures correctly and show some understanding of lower-order relations. Following this, children were presented with three parts of an analogy sequence (e.g., automobile, gas, sailboat) and then asked to find the appropriate relation that would complete the analogy from a selection of possible distractors, including the correct answer (e.g., travel/wind/sails/rudder). If children did not find the pairing task easy, then hints were provided. If correct relational pairs were formed, children were given counter-suggestions to establish whether they had a grasp of the underlying relations. Only those children who could resist such counter-suggestions, and provide a suitable justification for their choices, were deemed capable of reasoning about higher-order relations. Based on their findings, Piaget *et al.* (1977) claimed that children can quite often explain the relation between the A and B terms and C and D terms but at the same time find it increasingly difficult to use the relation between A and B term to find a suitable match for the C term, thereby failing to demonstrate any evidence of using relational similarity. These pictorial tasks were especially difficult for children to solve before the stage of formal operations that typically begins to emerge around

the age of 11-12-years. According to Piaget, this provided sufficient evidence that young children were unable to reason analogically because of their limited understanding of higher-order relations. Therefore, prior to the formal operational stage of development, Piaget argued that children would fail to demonstrate a mature or well-developed understanding of relational similarity.

Based on these earlier preliminary investigations, Piaget, Montangero and Billeter (1977) defined three progressive stages in the development of analogical reasoning. These stages corresponded to Piaget's more general view of cognitive development: the preoperational stage around 5-to-6-years, the concrete operational stage up to 10 to 11 years and the formal operational stage from 11-years after.

The first stage of analogical reasoning, consistent in developmental terms with the preoperational stage, was found to emerge around 5 to 6 years of age. Piaget claimed that children at this stage had very little, if any, understanding of analogical reasoning. At this stage children had profound difficulty in recognising relations between pictures even those corresponding to first-order relations (A and B terms) and made very subjective pairings of objects that were generally incorrect. Thus, children in this stage had no understanding of any kind of relational similarity. The second stage relates to the period of concrete operations, around 7-to-8 years up to 10 to 11 years of age, and is marked by the ability to recognise relations between pictures, and occasionally recognise relational similarity. Children occasionally showed correct performance but also frequently accepted false counter-suggestions these were presented by the experimenter. There was no consistency in children's analogical reasoning performance and very few children were able to justify their choices when they were correct. The final stage of analogical development coincided with the formal operational stage, which develops around 11 years of age onwards. At this stage, according to Piaget, children show analogical performance with complete consistency. They are able to extract higher-

order relations and are able to apply their relational similarity to correctly solve analogical problems. Children at this stage are also able to justify their solutions in terms of relational similarity and furthermore avoid false counter-suggestions when presented by the experimenter. It is at this stage, that children are believed to have developed a complete understanding of relational similarity.

According to Piaget's theoretical position there are three fundamental claims to successful analogical reasoning. First, analogical reasoning using relational similarity does not emerge until the stage of formal operations when children have acquired the ability for abstract thought (around the age of 11-years). Second, reasoning about 'higher order' relations develops at a later stage than reasoning about 'lower order' relations. Third, whilst young children frequently accept false counter-suggestions rather than solving analogical problems based on the underlying relational similarity, older children can resist such counter-suggestions and reason according to their understanding of relational similarity. Although these claims form the basis for Piaget's structuralist approach to analogical reasoning, it will become evident throughout this Chapter that the empirical support for these theoretical claims is weak.

Experimental support for Piaget's model is limited (e.g. Gallagher & Wright, 1977, 1979; Levinson & Carpenter, 1974; Lunzer, 1965). The study conducted by Levinson and Carpenter (1974) however seems particularly worthy of mention as it is frequently cited in favour of Piaget's theoretical claims within the developmental literature. Levinson and Carpenter presented children, between the ages of 9, 12 and 15-years, with analogical problems situated in the classical A:B::C:D analogy format. Children were also asked to explain their answers. Two specific types of analogies were examined: quasi-analogies and true analogies. In quasi-analogies, the semantic features appropriate to the relations are provided which removes the need for making relational similarities (e.g., a bird requires air and a fish requires ?) whereas the true analogies required

children to work out both parts of the A:B and C:D terms for themselves and to apply the relation to complete the analogy correctly (e.g., bird: air :: fish: ?). Levinson and Carpenter (1974) found that 9-years-olds performed better on the quasi-analogies than they did on the true analogies. However, in comparison, the 12 and 15 year-old's performed equally as well on both the quasi-analogies and true analogies. There was also a significant increase with age in the number of explanations children gave regarding the relations they used to solve analogies correctly. However, an important limitation concerns the age range studied and the possibility that had younger children been included in the study they too might have also demonstrated high levels of responding on the quasi-analogies.

There is further evidence from a later study by Gallagher and Wright (1977). In their study, they attempted to replicate Piaget's earlier findings regarding the late development of relational reasoning but this time using written analogy problems, rather than pictorial stimuli. Children were also required to provide a written explanation for their choice of answer. Gallagher and Wright (1977), argued that presenting children with pictorial stimuli as prompts allows them to focus on observable features rather on relational similarity. In their study, children were presented with traditional classical analogy format 'automobile is to gas as sailboat is to (travel/wind/sails/rudder)'. Analogical performance was strongly related to age: younger children performed less accurately in solving the analogy sequence whereas older children showed evidence of using relational similarities. A percentage of 'symmetrical responses' were calculated according to children's explanations: a symmetrical response is based on the comparison of both halves of the analogy and is used as an index of higher-order reasoning, for example, reasoning according to the shared relations underlying both terms (A:B and C:D) rather than considering the relations underlying one term alone (C:D). The percentage of symmetrical responses was found to be significantly related to age even when IQ was

controlled using multiple regression analysis. According to Gallagher and Wright (1977), therefore, the use of higher-order relations is a typically later developing skill. These findings were taken as strong support for structuralist models of analogical development, although, it is important to note the limited and narrow age range studied in this research (10 to 12 years).

In a related paper, Gallagher and Wright (1979) compared the performance of 260 children between the ages of 9 to 12 year-old on two specific types of analogies: concrete analogies where solutions could be made on observable features and abstract analogies where solutions needed higher-order rules (or the use of relational similarity). They found that the performance of children of all ages was consistently high in solving the concrete analogy items but performance on the abstract items improved with age. They concluded that a shift in performance with solving abstract items occurs around the stage of formal operations after the age of 12 years. Moreover, as with Piaget's original experiments, they demonstrated that 9 year-old children more frequently accepted counter-suggestions presented to them and that they had extreme difficulty in explaining their correct choices. Gallagher and Wright (1979) suggest that children of this age were reasoning about successive relations rather than using relational similarity to solve the analogy problems.

However, this conclusion can be criticised. First, to provide a thorough assessment of Piaget's model, children of a younger age should have been included in the study to assess whether there was any evidence that younger children could also solve concrete analogies. This is important because this may have illustrated that some forms of analogical reasoning develop much earlier than originally hypothesised. Second, and perhaps more importantly, Gallagher and Wright included no pre-test measure of children's knowledge of the possible relations used in the analogy task, thus an important confound was their failure to measure appropriate domain knowledge. Therefore, it seems likely that the levels of poor performance shown by the 9 to 10 year-olds on

solving the abstract forms of analogy could have been due to either a lack of appropriate knowledge of the relations involved in the task or to an incomplete understanding of the nature of the task rather than to an inability to use relational similarity (Goswami, 1991).

It is important to note that Piaget's theoretical approach to the study of children's analogical development is based on a particular theoretical and philosophical interpretation of his observations and experiments with older children (until fairly recently). His theoretical claims for many years went remained largely unchallenged (see Goswami, 1991, 1992 1996). It is important to note, however, that Piaget's theoretical framework has a number of important methodological limitations that need to be addressed (some of which have already been outlined above).

First, it is important to recognise that Piaget (e.g. Inhelder & Piaget, 1958; Piaget *et al.*, 1977) presented a framework that was fundamentally theoretically driven rather than empirically motivated. Because his methods were based on theoretical interpretations of research evidence rather than strict empiricism, most of the support for his theory is extremely difficult to interpret and open to alternative suggestions (Goswami, 1991). Furthermore, contemporary developmental psychologists challenge Piaget's earlier investigations on the grounds that his methods were somewhat eclectic and that they are poorly documented (by modern, scientific standards). There is at least partial support to this claim. There is evidence from a series of more recent and well-controlled investigations which provide a clear illustration of how children from as early as 3, 4 and 5 years of age can reason about shared relations (e.g. Armbruster, Echols, & Brown, 1982; Brown & Kane, 1988; Brown, Kane, & Long, 1989; Crisafi & Brown, 1986; Goswami, 1989a, 1989b, 1995b; Goswami & Brown, 1990; Holyoak, Junn, & Billman, 1984; Holyoak & Koh, 1987).

Second, as briefly mentioned earlier, the experimental support for Piaget's claims is limited because the analogy tasks that have been used to assess relational

similarity are typically complex and are abstract in nature. Although studies by Levinson and Carpenter (1974) and Gallagher and Wright (1977, 1979) are frequently cited as providing strong evidence regarding the late development of analogical reasoning, neither of these studies provided a pre-test of domain knowledge. It could be argued, therefore, that the research findings may indicate that children's inability to complete analogy problems correctly is caused by a lack of appropriate knowledge of the relations used in the tasks. This suggests that presenting younger children with item analogies based on unfamiliar relations may seriously underestimate their ability to solve analogical reasoning problems.

Third, the finding that younger children are more prone to accepting false counter-suggestions than older children are, has been taken as strong evidence that children prior to the formal operations stage were unable to reason analogically using relational similarity. However, this interpretation may also be misguided (see Gallagher & Wright, 1979; Levinson & Carpenter, 1974; Lunzer, 1965). As before, the same possible confounds relating to appropriate relational knowledge could provide some explanation as to why young children made analogies based on associative rather than the relational terms. If young children have not yet acquired a conceptual understanding of the relations on which the analogy is based, then it is entirely likely that they will accept an incorrect counter-suggestion rather than using relational similarity appropriately. Failing to carry out appropriate measures of prior knowledge is, therefore, confounding the findings.

Fourth, there are also difficulties with the distinction made by Piaget between lower-order and higher-order relations. Piaget suggested in his theoretical approach that reasoning about higher-order relations (relational similarity) develops at a later stage than reasoning about associative relations or lower-order relations. The previous experiments, particularly those conducted by Lunzer (1965), Levinson and Carpenter (1974) and Gallagher and Wright (1977, 1979) would seem to support this distinction,

showing that children below the age of 11-years are incapable of reasoning by higher-order relations. However, this may not necessarily be the case because, as Goswami (1992) illustrates, the distinction between these two types of relations is flawed. The classification of whether a relation is lower-order or higher-order is dependent on the type of analogy used and on other types of relations that are included in the task. On one occasion the relations 'keeps warm' may be treated as a lower-order relation (as this links A and B terms) but on another occasion the same relation may be higher-order as this links both pair items (linking the A and B terms to the C and D term). Therefore, independently categorising relations as either lower or higher-order relations can be seen as being misleading and uninformative. According to Goswami (1992), what is more important is the child's understanding of how these pairs can be related to each other and an understanding that the same relation can link both pair items together to complete the analogy, irrespective of whether this involves lower or higher-order terms. The distinction between lower-order and higher-order relations, therefore, offers little to an understanding of children's analogical capabilities.

In summary, Piaget's theoretical claims regarding the late development of analogical abilities in childhood and the development of higher-order relational similarity to global shifts in competence have been largely criticised. More recently it has been argued that the development of appropriate domain knowledge and familiarity of underlying structural relations may be found to account for these apparent changes in analogical development rather than global age related shifts in logical development. It is also argued that the empirical evidence often cited in support of Piaget's claims could be open to alternative explanations (Goswami, 1992). Therefore, given these limitations, alternative approaches to the study of analogical reasoning will be considered next.

1.1.2. Gentner's Structure Mapping Theory of Analogy

Gentner's structure mapping theory is another well recognised theoretical approach to understanding the development of analogical reasoning that has received wide recognition within the cognitive developmental literature (e.g. Gentner, 1983, 1988b; Gentner & Rattermann, 1991; Gentner & Toupin, 1986). Gentner's structure mapping theory is based on studies of children's solution of problem analogies rather than classical analogies; however, her theory is similar to Piagetian theory in that she identified relational similarity as the focus of developmental change. Gentner's theory emphasises the importance of surface similarity (attribute/object-based) to young children and how, with age and increased knowledge, children become more sensitive to the underlying relational structure. Gentner's focus is on similarities in relational structures that are independent of the objects that are embedded in those relations. She proposes that, for young children, analogical transfer initially involves mapping a system of relations based on noticing common object similarities and this is later followed by a reliance on an understanding of shared relational structures.

The process of structure mapping is an important aspect of Gentner's theoretical approach and she suggests that children map knowledge from one base domain to a target domain in a way that preserves the relational structure. According to Gentner (Gentner, 1988a; Gentner, Rattermann, Markman, & Kotovsky, 1995), children's analogical reasoning ability ultimately depends on their ability to notice the relational commonalities between base and target domains independently from the object on which those relations are based. This ability to maximise relational similarities independently from competing object similarities is referred to as systematicity (Gentner & Toupin, 1986).

Implicit in this account is a relational shift characterising children's ability to process object-based commonalities followed by an ability to process relational commonalities: younger children demonstrate a tendency to focus primarily on common

object descriptions whilst older children focus on the underlying relational structure (Gentner & Rattermann, 1991; Gentner *et al.*, 1995). Within her account, Gentner defines a number of different types of object and relational similarities, the understanding of which develops through four different levels. Gentner argued that the earliest similarity matches are based on purely object-based similarity, often bound by perceptual features such as a shape, colour or size. An example would be children's ability to notice relations between a round red ball and a round red apple. Next, children recognise similarities between object attributes, such as a *red* ball is like a *red* car. After recognising such similarities between perceptual features, children begin to realise that relations are similar, beginning with first-order relations. For example, a *red* ball *rolling* on a table is analogous to a *red* car *rolling* on the floor. Finally, children recognise second-order relational similarities, for example, an appreciation that an apple falling from a tree *permitting* a cow to reach and eat it, is relationally similar to a red car rolling off a table *permitting* a child to reach it (examples taken from Gentner & Rattermann, 1991, p. 228-229). Gentner's proposal that the development of analogical reasoning involves a relational shift between object and relational similarity describes a developmental process that children progress through in order to develop appropriate skills in learning to reason by analogy. A child's development through these different processes also depends on the acquisition of the preceding type: 'the relational shift does not imply the disappearance of object similarity as a psychological factor, rather it refers to the possibility of making purely relational matches' (Gentner *et al.*, 1995, p. 275). This developmental process therefore depends on an increasing awareness about relations through a process of relying on object-based similarities to a more refined and detailed appreciation for higher order relational similarities (see Gentner *et al.*, 1995).

Gentner's theoretical model also implies that there is consistency in children's reasoning skills: younger children and novices do not show the same

relational focus as adults in reasoning by analogy instead they rely on mappings based on object or perceptual similarities when solving analogies (e.g. Gentner, 1983, 1988b; Gentner & Rattermann, 1991; Gentner & Toupin, 1986). However, it is important to note that this relational shift does not specifically reflect structural change. Gentner acknowledges that the relational shift may indeed simply reflect a genuine competence deficit or changes in increasing domain knowledge (see Gentner & Rattermann, 1999 for further discussion). According to Gentner, the relational shift is also dependent on the child's level of knowledge, occurring in different domains at different times, depending on the domain. Thus, according to Gentner, children's ability to use relational similarity to solve analogical reasoning problems depends on their underlying conceptual knowledge of a particular domain rather than on their developmental age or stage as Piaget initially proposed.

Although there is support that young children rely solely on surface similarity when they engage in analogical reasoning (e.g. Chen & Daehler, 1989; Daehler & Chen, 1993; Gentner & Toupin, 1986; Pierce & Gholson, 1994; Rattermann & Gentner, 1998) there are only two studies that provide a specific measure of the relational shift theory (Gentner & Toupin, 1986; Rattermann, Gentner & DeLoache, 1989). Included in these two studies is a cross mapping task designed to assess systematicity and analogical transfer in young children. The cross-mapping tasks were designed to disentangle the possible confounding effects between object and relational similarity in young children's analogical reasoning by presenting a situation whereby object similarities support one base-target mapping whilst relational similarities (independent to perceptual similarity) supported another base-target mapping.

Gentner and Toupin (1986) examined evidence in support of the relational shift in the development of analogical reasoning with children between the ages of 4-to-6 and 8-to-10-years. They designed a story-mapping task in which the analogical

component needed to be transferred from one story plot to another. Systematicity was manipulated by including an explicit causal structure to some of the stories, which contained a strong moral at the end (e.g., the cat realised the importance of not being jealous). Children listened to one story and acted it out with one set of animal characters representing a hero, villain and friend. The test of analogical reasoning was to see whether these children could transfer the initial story to a new set of animal characters that fulfilled the roles of hero, villain and friend. Surface similarity was systematically controlled: the animal characters in the base and target stories were either similar in appearance (e.g., chipmunk- squirrel, robin-bluebird) or perceptually different (chipmunk-elephant, robin-shark). Their findings provided strong support for systematicity and surface similarity. In their analyses only the 8 to 10 year-olds showed superior levels of transfer between base and target stories when the moral was provided. There was also clear evidence of a shift between 6 and 9-years: although surface similarity strongly affects transfer for both age groups, only the older children benefited from the presence of high order relational structures. However, given that the story-mapping task required children to understand quite sophisticated motivations, such as greed and jealousy, no control task was used in the study to establish that the 4 to 6 year-olds understood these relations (Goswami, 1991). Similarly, there is evidence to show that young children do not necessarily lack relational focus when the explicit goal structure is made evident to them (Brown, Kane, & Echols, 1986; Holyoak *et al.*, 1984; Holyoak & Koh, 1987).

In a related study, Rattermann, Gentner and DeLoache (1989) investigated relational similarities in a cross-mapping task with 3 to 4 year-olds using sets of physical objects. The child and experimenter each had a set of three objects which displayed a monotonic increase in size. Children observed the experimenter place a sticker underneath one of their own objects and then asked the child to search for a corresponding

sticker under the equivalent object in their own set. However, the correct mapping was always based on the objects' relative size and not necessarily the objects perceptual similarity. To compare the effects of object similarity against relational similarity, a cross mapping between the two triads were achieved by staggering the sizes of the two triads (e.g., experimenters set contained 1, 2, 3 the child's set contained 2, 3, and 4). The logic of the task was to pit object similarity against relational similarity and systematically examine whether young children would carry out the relational mappings between the two structures. The results revealed that 3 year-olds were mainly performing analogical mappings based on object similarity (e.g., perceptual features) whilst 4 year-old children were able to ignore mappings based on shared object similarities, and make appropriate mappings based on shared relational structure. Thus, whilst younger children's performance was impeded by perceptual similarities between objects, older children were more resilient, relying on relational structures more frequently than the 3 year-old's.

However, an important limitation in this research is the possible confound associated with appropriate domain knowledge. The findings from these studies are limited as they neglected to assess children's knowledge of the particular relations used in the analogy tasks. For example, in the Rattermann, Gentner and DeLoache (1989) study discussed previously, when presented with two sets of objects that displayed a monotonic increase in size, 3 year-olds were unable to correctly map the relative size of an object between two competing sets. This was taken as strong support for the relational shift hypothesis. However, when the objects were labelled according to ordering of height relating to a familiar 'family' schema (e.g., daddy > mommy > baby), 3 year-olds performance increased significantly showing evidence of mapping relations between the two sets of objects which was previously difficult for children of this age to achieve. Indeed, under these new conditions, the 3 year-olds mapped relations very efficiently. Thus, using familiar relations as a basis for presenting analogies enables children to solve

analogical problems correctly. Goswami (1995b) also presents a similar example of the facilitative effects of a familiar schema based on daddy bear > mommy bear > baby bear as an aid to successful analogical performance in 3 to 4 year-old children. Furthermore, in support of a domain knowledge interpretation, there is fairly widespread agreement that children as young as 3 and 4 years of age are capable of reasoning about relations using problems which are appropriate to the child's level of understanding (e.g. Armbruster *et al.*, 1982; Brown, 1989; Brown & Kane, 1988; Brown *et al.*, 1989; Crisafi & Brown, 1986; Ferrara, Brown, & Campione, 1986; Holyoak *et al.*, 1984; Holyoak & Koh, 1987). The proposed relational shift from object similarities to relational similarities documented by Gentner may, therefore, be a function of domain knowledge rather than a competence deficit in analogical ability (see also Goswami, 1991).

1.1.3. A Knowledge-Based View of Analogy

Goswami's (1992) knowledge-based view focuses on appropriate domain knowledge as a key prerequisite for analogical success in young children, thereby directly addressing some of the limitations implicit within previous accounts of analogical reasoning. Knowledge-based accounts assume that the relational shift results from changes in knowledge, and not from global or maturational changes in development (Brown, 1989, 1990; Brown & Kane, 1988; Chen & Daehler, 1989, 1992; Crisafi & Brown, 1986; Goswami, 1992; Vosniadou, 1989; 1995). Although Goswami's account predicts that children's analogical performance will develop with age as children develop more knowledge, in contrast to the theories of Piaget and Gentner, it does not predict global shifts in analogical reasoning ability with increasing age. According to the knowledge-based view of analogical reasoning, relational familiarity is an important prerequisite to the development of successful reasoning. Furthermore, there is evidence showing that young children can use analogies efficiently when age appropriate materials are used to

assess analogical performance (e.g. Armbruster *et al.*, 1982; Brown & Kane, 1988; Brown *et al.*, 1989; Crisafi & Brown, 1986; Goswami, 1989a, 1989b, 1995b; Goswami & Brown, 1990; Holyoak *et al.*, 1984; Holyoak & Koh, 1987).

In addition to the use of story-based analogical problems, young children are able to solve classic A:B::C:D analogies provided they have the requisite knowledge. (These are the types of analogy problem, which, according to Piaget, young children find extremely difficult to solve before the stage of formal operations). In an early prominent study, Goswami and Brown (1990), examined young children's analogical performance using a task based on physical thematic relations. Children aged 4, 5 and 6 years were presented with a series of pictorial A:B::C:D analogies around familiar thematic relations. To examine relational knowledge independently from analogical performance, children were given an analogy condition and a thematic control condition, designed to assess relational knowledge and to ensure that unfamiliar relations did not underestimate analogical ability. For each trial, children were asked to complete the analogy by choosing the correct picture from a choice of four competing alternatives (e.g., the correct answer, and associative, semantic, and perceptual similarity distractors). In order to complete the analogy successfully, children had to understand the appropriate thematic relation between the A and B term (e.g., 'lives in') and map this to the C and D term to correctly complete the analogy sequence based on relational similarity. All children (4, 6, and 9 year-olds) performed well with mean scores of 59% correct for 4 year-olds, 66% correct for 6 year-olds and 94% correct for 9 year-olds. This effect was also found to be robust across different contexts. For example, in a subsequent study, Goswami, (1989a), examined analogical reasoning based on shared causal relations, such as wetting, cutting and melting, and found equivalent levels of performance in children of the same age. Overall, the 3 year-olds solved 52% of the analogies, the 4 year-olds solved 89% of analogies and the 6 year-olds solved 99% of analogies with feedback. The

results obtained in these studies provide convincing support for the suggestion that children are capable of solving analogical reasoning tasks as long as they have the relevant knowledge of appropriate relations and detailed understanding of task requirements (Goswami, 1992, 1996). Goswami (1992) argues that analogical reasoning was knowledge dependent such that as long as the relations underlying an analogy were understood then success was relatively inevitable on the basis of similarity mapping. According to the knowledge-based view, familiarity of relations, therefore, governs children's analogical success.

There is considerable evidence that demonstrates how the positions of Goswami and Brown can be encompassed within a knowledge-based account of the relational shift in analogical development. However, their position is somewhat more complex and extends beyond this interpretation. Goswami and Brown both stress the relative importance and early availability of relational similarity from early infancy (Brown, 1989, 1990; Goswami, 1992, 1996, 2001a). They place greater emphasis on the primacy of relations in early infancy and childhood. In support of this, there is strong evidence that analogical reasoning occurs in young infants and toddlers (e.g. Chen & Daehler, 1992; Chen, Sanchez, & Campbell, 1997; Freeman, 1996; Marcus, Vijayan, Rao, Bandi, & Vishton, 1999).

Freeman (1996) devised a series of analogies using real objects and models to assess 2 year-olds ability to reason about relational similarity. These analogies were based on simple causal relations including *fixing*, *stretching*, *rolling*, *breaking*, *opening* and *attaching*. Children were presented with three analogy problems. The first problem was completed by the experimenter and provided a base from which children could make the analogy. To provide an example, using the *stretching* relation, children were shown how an elastic band could be stretched around two poles to make a bridge to roll an orange across. The second (e.g., helping a bird to fly) and the third (e.g., giving a

doll a ride) analogy problems provided a different context but were isomorphic: the same procedure of stretching the elastic bands around two poles could be used to solve the problem successfully. To solve the problem, children were required to transport the object and work out that regardless of the object used (e.g., orange, bird, doll) the appropriate device (e.g., elastic band) could be used to solve the problem. Freeman also included a control condition to assess spontaneous analogical transfer without explicit instruction. Children in the control condition were asked to complete the target problems (e.g., give the doll a ride and help the bird fly) without first seeing the base problem. Interestingly, over the six different trials, 28% of all 2 year-olds used the correct causal relation to solve the analogy problems, which rose to 48% after receiving explicit hints (this is compared to 6% without and 14% with hints for those children in the control condition). Further examples of relational reasoning in infants and young children can be found in studies by Chen et al, (1997) and Marcus et al, (1999).

In summary, the knowledge-based view regarding the development of analogical reasoning seems to provide a more compelling account of children's analogical development than previous structuralist models (c.f. Inhelder & Piaget, 1958; Piaget *et al.*, 1977). The chapter has so far outlined some important considerations relating to the study of children's analogical reasoning: these are to ensure that task requirements are not too difficult for young children, to ensure the use of relations are familiar to child, and finally the need to ensure that children already have some appropriate knowledge of the domain being tested (see Vosniadou, 1995). Given that analogical reasoning skills appear to develop from a relatively early age, it is likely that they will have important implications for children's experiential learning and development within different educational contexts. This issue is discussed in detail in the following section. (The classical analogy tasks discussed in this section are types of reasoning tasks that are less obviously linked to any one specific area of educational knowledge, such as

the phonological knowledge needed for reading or the knowledge of addition principles necessary for mathematics. For this reason they will be referred to as ‘traditional analogical reasoning’ tasks in the remainder of this thesis).

1.2. Analogical Reasoning in Specific Domains

Having argued that traditional forms of analogical reasoning are important for children’s cognitive development (Brown, 1989; Gentner & Clement, 1988; Goswami, 1991, 1996, 2001a; Halford, 1992, 1993; Holyoak, 1985; Holyoak & Thagard, 1995) and that such reasoning skills appear to be available early in childhood, with a number of studies demonstrating analogical skills in 1, 2 and 3 year-olds (e.g. Brown & Kane, 1988; Brown *et al.*, 1989; Chen *et al.*, 1997; Crisafi & Brown, 1986; Freeman, 1996; Goswami, 1989a, 1989b; Goswami & Brown, 1990) it is important to consider the development of analogy use across different educational contexts. Given the potential power of analogical reasoning in children’s learning, reasoning and knowledge acquisition, this raises the possibility that they have the potential to play an important role in developing young children’s knowledge within different educational domains. It also raises the possibility that there may be strong similarities in the manner that children approach solving analogical problems across these different contexts. This issue is considered in more detail in the following section.

1.2.1. Similarities in Analogy Skills across Domains

It has been proposed that analogical reasoning constitutes both a domain-specific mechanism (found to work within particular domains once a certain degree of relational knowledge about the domain has been acquired) and a domain-general mechanism (facilitating reasoning across different domains) (Carey & Spelke, 1994; Gelman & Williams, 1998). However, a number of theoretical questions are raised concerning the

extent to which analogical reasoning skills may be constrained to a particular domain, such as reading or mathematics, or whether there are any similarities or consistencies in the way young children approach analogical problems across different educational domains. For example, processing relations leads to conceptual change within the given domain (Carey & Spelke, 1994), however, the ways in which analogical skills can promote such changes in children's reading and addition skills is far from clear. An examination, therefore, of how children use analogical reasoning to develop their understanding and knowledge of reading and mathematics is needed.

In terms of the present research, the two domains of interest are reading and mathematics. The specific educational contexts within these two domains that are examined are those of children's reading (i.e., knowledge of phonological relations) and addition (i.e., knowledge of formal addition principles). It is expected that exploring the possibility of identifying similarities in children's analogical reasoning skills across these two specific educational contexts may lead to a more detailed account of children's cognitive development.

There is increasing evidence that children are able to use analogies as a way of developing their domain knowledge within a range of different educational contexts. For example, children frequently use analogies to aid their understanding of biology (Inagaki & Hatano, 1987), physics (Goswami, Pauen, & Wilkening, 1996), mathematics (Singer-Freeman & Goswami, 2001; Spinillo & Bryant, 1991, 1999) and reading (Goswami, 1993). Given the breadth of research, there is very little doubt that analogical reasoning strategies can be used within a variety of different contexts to promote learning and development. However, the possibility that children's analogical development in reasoning is similar across these different contexts has not been examined because each study has tended to focus solely on the use of analogies in that domain alone. A useful contribution to our current knowledge of analogical reasoning, therefore,

would be a systematic comparison of children's use of analogical reasoning skills across two or more domains and an assessment of whether gains in analogical reasoning within one domain are accompanied by gains in analogical reasoning skills in other domains.

There is also at least some theoretical suggestion that similar levels of analogical reasoning will emerge when children's reasoning abilities are compared across different educational contexts. For example, there are suggestions that analogical reasoning makes a contribution to cognitive development by being a domain general reasoning process available to young children as a way of acquiring, structuring and restructuring knowledge across different contexts or domains (see Carey & Gelman, 1991; Carey & Spelke, 1994; Gelman & Williams, 1998; Goswami, 1996). Also, according to some theorists, conceptual knowledge is developed by processing relations, which leads to conceptual change within and across different domains of knowledge (Carey & Spelke, 1994). However, the ways in which analogical reasoning can actually promote such changes in domains is currently unclear. Furthermore, the possibility that similar levels of relational reasoning can be found across different domains has not yet been examined empirically. A central theme underlying the present research, therefore, is to provide a detailed examination of the salience of analogical reasoning skills in the context of reading and addition and the identification of possible commonalities in children's early reasoning abilities across the two specific domains of reading and mathematics.

In the present research, the term analogy is used in its broadest sense, to examine children's ability to reason about relational similarity in the context of reading and addition. According to both Piaget and Gentner, young children should not show any evidence of analogy use in either reading or addition given the late development of analogical reasoning skills. In contrast, according to Goswami's knowledge-based view, which assumes that young children develop a relatively early understanding of domain related knowledge in reading and addition and that the relevant relations are

familiar to the child, then it can be predicted that they should use their knowledge of these relations as a basis for making analogies. There is strong evidence that this may be the case because children do appear to develop an early appreciation for knowledge relations within both of these two contexts, including phonological relations in reading (Goswami, 1993; Goswami & Bryant, 1990) and relations grounded on formal addition principles in simple addition (Canobi, Reeve, & Pattison, 1998, 2002; Sophian, Harley, & Martin, 1995a; Sophian, Wood, & Vong, 1995b).

Children's ability to look for, and identify, relations among similar related problems in reading and addition will be examined. However, although it is claimed throughout this thesis that there is a need to consider children's analogical reasoning skills in each of these contexts, looking at children's analogical performance within these two areas independently provides a limited understanding of analogy. To fully understand the development of analogical reasoning, it is important to examine the children's performance on solving analogical reasoning tasks across different contexts together.

It is argued that the most efficient method for looking at possible similarities across the two contexts of reading and addition is to classify children's patterns of responses to solving analogical problems in reading and addition together using cluster analytic techniques. These techniques have the potential to identify different patterns of responses, or subgroups of children, according to the efficiency they demonstrate in solving conceptually related problems across the two domains. There is some work in the context of children's addition that shows how examining patterns of responses in children's addition knowledge is an important indicator of their underlying mathematical understanding (c.f. Canobi *et al.*, 1998, 2002, 2003). We do not really know, however, whether this is true of the reading domain. Therefore, the present research proposes to explore analogy in both reading and addition by looking for differences in the patterns of knowledge displayed by individual children or subgroups of children.

Exploring similarities across reading and addition is important because this examination may help provide a more detailed theoretical account of analogical reasoning and shed light on its relationship to cognitive development. Looking for links between patterns of performance in each domain will also establish whether there is a common analogical mechanism underlying children's performance in both the domain of reading and mathematics.

1.2.2. Contribution of Traditional Reasoning Skills

Although it has been argued that examining possible links in children's analogical reasoning skills within specific domains or contexts, such as reading and addition, is important, it is also necessary to address its relationship to cognitive development in more general ways. According to traditional accounts of reasoning development (e.g. Inhelder & Piaget, 1958; Piaget *et al.*, 1977), children's ability to use analogical reasoning skills in different contexts simply reflects a more basic and general capacity to look for and analyse relations between problems that can be applied within a variety of tasks across domains. This claim, however, has not been examined empirically.

There is a strong tradition of assuming that children's ability to use analogies in specific domains is indicative of their appropriate domain knowledge rather than their general reasoning abilities. For example, in reading and addition, there is a tendency to assume that young children's ability to reason about relations is embedded deeply within their domain skills and concepts and not related to other forms of analogical reasoning (see Wellman & Gelman, 1998). This would imply that reasoning skills, once embedded within specific contexts such as reading or mathematics, are not bound by domain general principles but instead they are constrained solely by children's domain knowledge and expertise within that particular domain itself. A useful way to explore this issue is to examine relations between analogical reasoning in reading and addition with other forms

of ‘traditional analogical reasoning’ skills that are less related to these specific domains, such as the ability to solve analogies based on visual, causal and thematic relations.

It is currently unknown whether children’s ability to use analogies in early reading is related to other more general forms of analogical reasoning tasks (outside the reading domain). This is important because it is necessary to address whether analogies in reading reflect a general capacity to look for and analyse relations between problems that can be applied within a variety of tasks across domains or alternatively whether young children’s ability to reason about relations in reading is embedded within their reading skills and concepts and not related to other forms of analogical reasoning. There is some suggestion that performance on traditional forms of analogical reasoning tasks might have an influence on how children use analogies in reading (see Wood, 1999). However, if this is the case, and the use of analogies in reading is domain-general, such a finding would have far reaching theoretical and practical implications. This would imply that reading researchers might need to develop a more detailed theoretical model that includes a more interactive account of the development of analogical reasoning skills in early reading, rather than focussing exclusively on orthographic analogies.

Unlike the context of reading, however, there has been no systematic examination of whether general forms of analogical reasoning skills are closely related to children’s use of analogies within addition. There are, nonetheless, strong claims that children’s ability to learn and reason arithmetically with natural numbers is guided by domain-specific principles and concepts within addition itself (see Gelman, 2000). Implicit in this discussion is that a domain-specific approach to understanding number development is appropriate and that children’s reasoning about natural numbers is guided by knowledge requirements within the domain rather than concepts outside of this domain. It is possible that examining the relationship between children’s use of analogies in addition and other

forms of traditional analogical reasoning skills will have important implications for cognitive models of addition development.

In summary, there is a need for further research to examine the relationship between analogical reasoning and cognitive development more closely. Although it is already well established that knowledge of relations or concepts within a domain is important for the child's ability to use analogies within the particular domain, a more important question to ask is whether analogical relations are the key for children to notice similarities across a variety of different contexts or domains together and whether this simply reflects a more global ability to reason analogically.

1.3. Chapter Summary

This chapter has reviewed the most influential theories of analogical reasoning and has outlined the implications that these may have for understanding children's cognitive development. According to the traditional Piagetian approach, analogical reasoning is a fundamentally sophisticated skill that does not emerge prior to formal operations around the age of 11-years. Piaget's approach reflects maturational, domain-general shifts in analogical reasoning, suggesting that children become 'domain-general' reasoners as they become older and more experienced (see Goswami, 1991). According to Gentner's structure mapping approach, the ability to reason about objects relations develops prior to the ability to reason about relational similarity and reasoning about lower-order relations is available at an earlier age than reasoning about higher-order relations (e.g. Gentner, 1983, 1988b; Gentner & Rattermann, 1991; Gentner & Toupin, 1986). Although this seems to reflect a maturational and domain-general shift in reasoning, Gentner does acknowledge that this shift occurs with increasing knowledge within domains. Both of these theoretical accounts, however, are limited as the experimental investigations that support them failed to take children's existing domain knowledge into

account. Moreover, the analogy problems presented to children were complex and abstract and this may have presented additional difficulties for young children. It was argued that a knowledge-based view of analogical reasoning presents the most convincing model for understanding analogical development. There are countless examples demonstrating how young children are able to solve analogical problems from as early as 1, 2 and 3 years, especially when they hold appropriate knowledge of the domain (e.g. Armbruster *et al.*, 1982; Brown, 1989; Brown & Kane, 1988; Brown *et al.*, 1989; Crisafi & Brown, 1986; Ferrara *et al.*, 1986; Holyoak *et al.*, 1984; Holyoak & Koh, 1987). There is considerable support for the claim that relational knowledge is an important prerequisite to analogical success (Goswami, 1996, 2001a). If analogical reasoning has an important role to play in the development of new knowledge, then young children should use the knowledge that they already possess about a domain as a basis for seeking new relational similarity between existing and new knowledge and this should be apparent across many different contexts or situations.

Another important point made in this chapter regards the prominence of analogies in different educational contexts. Given that analogical reasoning has important implications for children's learning, reasoning, knowledge acquisition, and conceptual change (see Goswami, 1996), it is likely that the ability to reason using analogy will be integral to children's educational development within and across different contexts. Although there is considerable support for the role of analogy within specific educational contexts, including reading, science and mathematics, the possibility of identifying any commonalities in the way children use analogies across these domains has not been examined experimentally. In order to fully appreciate the importance of analogy, and to provide a more detailed understanding of the contribution of analogical reasoning to children's educational development, it is argued that a closer examination of children's reasoning skills across different domains is needed.

A related point is the need to consider how children's use of analogies in the context of reading and addition tasks is related to their performance on more traditional forms of analogical reasoning tasks. This kind of examination will help to clarify whether the use of analogical reasoning in reading and addition is a domain specific skill or alternatively whether this is part of a more general analogical reasoning ability. To examine this possibility, research is needed that compares children's use of analogical reasoning within specific contexts such as reading or addition against their performance on more traditional forms of analogical reasoning tasks (based on causal, thematic and visual relations).

The following chapters offer a detailed evaluation of empirical evidence concerning the role of analogical reasoning in the specific contexts of early reading and addition. A suitable framework for examining individual differences in children's development within these different educational contexts will also be outlined. In Chapter 2, the salience of analogy in children's reading is considered and a detailed rationale for exploring individual differences in children's use of orthographic and phonological relations is presented. In Chapter 3, the potential importance of analogies in children's addition knowledge and its relationship to problem solving is outlined and alternative methodologies to examine analogical reasoning skills in addition are discussed. Finally, a summary of the theoretical questions that motivated this research and a description of the four empirical studies alongside working hypotheses are presented in Chapter 4.

CHAPTER TWO

ANALOGICAL REASONING IN CHILDREN'S READING

2. Introduction

The purpose of this chapter is to examine children's use of analogical reasoning in the context of reading and to illustrate the importance of considering individual differences in children's use of orthographic and phonological relations more closely. It is recommended that this can be achieved by looking for differences in the patterns of knowledge displayed by individual children or subgroups of children. This may illustrate different pathways to reading development that are not evident in current theoretical models of reading. It is also argued that to acknowledge individual differences in children's use of orthographic and phonological relations in reading fully, it is important to examine the different kinds of strategies children use in their word reading and whether they show any consistency in their use of analogical reasoning. These issues are central to the present research and are addressed in the following sections.

In order to provide a detailed background to this discussion, previous research into children's reading development and the importance of domain knowledge is presented. Current theoretical models of reading development are then presented and the extent to which they emphasise analogical reasoning is reviewed. After demonstrating the importance of children's use of analogies in early reading, and the possibility of using new approaches to study analogical reasoning, methodological concerns are addressed. It is argued that although research has provided a fairly detailed picture of age related changes in children's analogical reasoning skills, very little is known about the development of individual differences in orthographic analogy use. It is claimed that a

more detailed understanding of analogical reasoning in reading can be achieved by looking for differences in the patterns of knowledge displayed by individual children or subgroups of children. Finally, it is argued that new research methodologies designed to assess whether children are strategically applying analogies to read new, unfamiliar words are needed.

2.1. Domain Knowledge in Reading

In order to understand young children's use of analogies in reading, it is important to identify what skills underlie analogical reasoning. The relations that a child needs to develop in order to make orthographic analogies during reading are sound relations or phonological relations that operate in the language that the children are attempting to read. As long as children have developed an underlying representation of relevant phonological knowledge and have a basis for making an orthographic analogy in their vocabulary, then there should be clear evidence that beginning readers can use analogies to assist their early word reading (see Goswami, 1993). The following sections will show how phonological awareness and orthographic knowledge each contribute to children's progression in learning to read and how children's use of analogical reasoning is intimately linked to their alphabetic knowledge. The literature concerning the development of children's phonological awareness also provides a useful framework for exploring children's use of analogies during reading as it has been established that (a) children have an early awareness of both onset-rime and phonemes and (b) both these phonological structures are important to reasoning by analogy in the reading domain.

2.1.1. Phonological Units in Reading

Children's phonological skills play a crucial role in their reading development (see Adams, 1990; Goswami, 2000; Goswami & Bryant, 1990; Kamil, Mosenthal, Pearson, &

Barr, 2000; Metsala & Ehri, 1998; Oakhill & Beard, 1999) and therefore are likely to play an important role in analogical reasoning. Specifically, it is argued that because young children develop a relatively early awareness of rhyme and phonemes, and these phonological structures provide an independent contribution to early reading development, then children will be able to use these phonological structures as a basis for making inferences or predictions about the spelling-sound patterns of new words in reading (Goswami, 1993; Goswami & Bryant, 1990).

The term phonological awareness is a global one, referring to an individual's ability to recognise smaller units of sound within spoken words. It is thus defined as the ability to perceive and manipulate the sounds of spoken words (Mattingly, 1972). Three important levels of phonological awareness have been distinguished within the reading literature (Adams, 1990; Goswami & Bryant, 1990). The first phonological distinction that emerges is at the level of the syllable. Syllabic awareness refers to children's ability to detect constituent syllables in words and is the earliest to emerge developmentally. The second phonological distinction is that between onsets and rimes. The onset of the word corresponds to the initial consonants in the first syllable and the rime corresponds to the vowel and any following consonants after the vowel. The final phonological distinction is that of the phoneme. Phonemic awareness refers to the ability to separate words into their individual constituent sounds. The different levels in phonological awareness are considered to reflect a developmental progression in learning to read (Goswami & Bryant, 1990). The awareness of syllables, onsets and rimes appears to emerge around 3-to-4-years before the child enters formal schooling. The awareness of phonemes, by contrast, appears to emerge around the age of 5 and 6-years when children are taught to read formally. This is because phonemic judgements are often difficult for young children to grasp without any prior reading experience (Goswami, 1999b). Phonemic awareness is likely to be confounded by alphabetic awareness, which by definition points

to the significance of orthographic knowledge for children to grasp the final sophisticated stage of phonemic awareness. Therefore, whilst awareness of onsets and rimes appear to be a precursor to reading, the explicit awareness of phonemes appears to be the result of explicit reading tuition and experience (although see Wood, 2004). According to these accounts, children who develop good phonological skills will become more efficient in reading and spelling than children with poor phonological skills (Goswami, 1999a).

2.1.2. The Development of Phonological Skills

Experimental support for the claim that the development of phonological skills may play a causal role in children's reading acquisition has developed from two specific lines of enquiry using different analytical approaches (see Adams, 1990; Castles & Coltheart, 2004; Goswami & Bryant, 1990; Wagner & Torgesen, 1987 for reviews). The first is concurrent correlations, where phonological awareness and reading ability are measured at the same point in time. The second is predictive correlations where phonological skills are measured at one point in time and reading ability at a later stage in development (Bradley & Bryant, 1983; Cunningham, 1990; Lundberg, Frost, & Peterson, 1988; Lundberg, Olofsson, & Wall, 1980; Morais, Alegria, & Content, 1987; Snowling, 1980; Wagner, 1988; Wagner, Torgesen, & Rashotte, 1994). Rather than simply assessing phonological awareness as a global term, it is more useful to assess the contribution of each of the different phonological units to reading, independently. Exploring specific links between onset-rime and phoneme skills and children's progress in learning to read will help to identify whether these skills offer an independent contribution to children's overall development in learning to read.

There are suggestions that children's understanding of intra-syllabic units, such as onsets and rime, will make a unique contribution to analogical reasoning skills within reading (Goswami & Bryant, 1990). An important claim within the reading literature is

that of an independent and unique relationship between phonological understanding of onset-rime and subsequent reading acquisition. The existence of a causal relationship between rhyme and reading development has been confirmed in a number of longitudinal and cross sectional studies (Bowey & Francis, 1991; Bradley & Bryant, 1983; Bryant, Bradley, MacLean, & Crossland, 1989; Bryant, MacLean, & Bradley, 1990a; Bryant, MacLean, Bradley, & Crossland, 1990b; Chaney, 1992, 1994, 1998; Fernandez-Fein & Baker, 1997; Kirtley, Bryant, MacLean, & Bradley, 1989; MacLean, Bryant, & Bradley, 1987; Stahl & Murray, 1994; Walton, 1995; Wood & Terrell, 1998). For example, in an early prominent study, Bradley and Bryant (1983) reported findings from a longitudinal investigation that systematically measured onset-rime and reading development from the age of 4 to 5 years and assessed reading in a follow up study at 8 and 9 years of age. They found that rhyme awareness measured in preschoolers was a significant predictor of their later progress in reading and spelling even after other variables, including vocabulary, memory and IQ had been taken into account. In a later study, Bryant and colleagues (1990b) report a significant relationship between children's rhyming skills and knowledge of nursery rhymes at age 3 and their success in reading and spelling at ages 5 and 6, even after systematically controlling for social background and IQ. Despite providing converging evidence for the relationship between rhyme awareness and reading development, however, failing to control for the autoregressive effects of reading ability raises concerns regarding the extent to which pre-existing reading skills artificially inflate phonological awareness scores in early reading (see Castles & Coltheart, 2004 for discussion). Aside from this limitation, there is evidence to support the claim that rhyme awareness does make a unique and independent contribution to reading acquisition in young children. If we accept Goswami's knowledge-based theory of analogical reasoning then it is reasonable to suppose that children's knowledge of onset-rime may make a

direct, unique contribution to their ability to reason analogically about spelling-sound patterns within reading.

There is convincing support, however, for a relationship between children's understanding of phonemes and their reading acquisition. Strong connections between phonemes and reading success have been found in both cross-sectional and correlational types of investigations (e.g. Cardoso-Martins, 1995; Høien, Lundberg, Stanovich, & Bjaalid, 1995; Hulme *et al.*, 2002; Muter, Hulme, Snowling, & Taylor, 1997; Nation & Hulme, 1997; Wagner *et al.*, 1994; Wagner *et al.*, 1997; Wood, 2000; Wood & Terrell, 1998). Nation and Hulme (1997) found that phoneme segmentation predicted significant variance in reading ability but onset-rime segmentation offered no further contribution once phoneme skills were taken into account. Hulme *et al.* (2002) found that once age, reading ability and vocabulary were accounted for, composite measures of phonemic awareness provided a significant and longitudinal prediction of reading ability 7-14 months later. Similarly, Stuart (1995) found that initial and final phoneme segmentation could accurately predict reading age a year later, even when early reading skills were taken into account. Overall, the significant contribution of phonemic skills to reading and spelling development is striking and suggests that children's underlying knowledge of such phonemic structure may also be important to their ability to use analogies when learning to read. However, it is important to note that there is some strong debate surrounding the importance of rhyme and phonemes as important predictors of reading development (see Bryant, 1998; Goswami, 2002; Hulme *et al.*, 2002; Hulme, Muter, & Snowling, 1998; Muter *et al.*, 1997).

Taken together, these studies have provided converging evidence in support of a strong developmental trend in phonological awareness, that progresses from syllable level, to the onset-rime level and the phoneme level (see Goswami & Bryant, 1990). Both rhyme and phoneme-related skills have been found to make a

significant contribution to the reading domain and these phonological skills are highly correlated to reading (Anthony & Lonigan, 2004; Anthony *et al.*, 2002; Lonigan, Burgess, Anthony, & Barker, 1998). Having established that young children develop a relatively early understanding of phonological relations in reading, the next step is to consider how an awareness of these phonological relations provides children with an additional strategy for linking spoken words to orthographic spelling units in word reading. It is argued that these links provide children with the ability to make inferences or analogies about new words (see Goswami, 1993; Goswami & Bryant, 1990).

2.2. Analogies in the Context of Reading

One of the most difficult tasks a child faces when learning to read is the need to relate orthographic structure to phonology. It is proposed that young children make this association by making inferences on the basis of shared spelling-sound correspondences between conceptually related words (Goswami, 1993). The ability to make inferences or predictions about the spelling-sound patterns in words forms the basis of analogy and it is argued that the use of orthographic analogy in children's word reading depends on their knowledge of phonological relations. As discussed in Section 2.1, young children develop an early understanding of phonological relations and therefore already have a good basis for making analogies within the context of word reading.

The goal of this section is to evaluate some of the previous research that has examined children's use of analogies in early word reading and to address some of the limitations with these studies. It is argued that there is a need to consider alternative pathways to reading development that are not found in existing theories of reading. It is also claimed that considering individual differences in children's analogical reasoning skills will help to provide a more detailed understanding of reading development.

2.2.1. Theoretical Models of Rhyme and Analogy

There are a number of influential theoretical accounts of reading development, which emphasise the importance of using phonological relations to decipher or decode the orthographic structure of unfamiliar words (Ehri, 1995, 1998; Frith, 1985; Goswami & Bryant, 1990; Goswami, 1993; Marsh, Desberg, & Cooper, 1977; Marsh, Friedman, Welch, & Desberg, 1981). There are two prominent models of beginning reading development that suggest distinct roles for phonological awareness proposed by Ehri (1995, 1998) and Goswami (1993, 1998; Goswami & Bryant, 1990). Both of these models agree that phonological abilities are essential to the children's progress in learning to read a regular orthography. However, disagreement continues over the size of the phonological units, corresponding orthographic representations and the strategies that are needed for developing reading skills in children's reading (see Bowey, 2002; Bryant, 2002; Goswami, 2002; Hulme *et al.*, 2002 for discussions). It is argued in this chapter that aspects of both phonological units are important to reading and that the two approaches by Goswami and Ehri may be reconciled by considering individual differences in children's early reading.

Each of these current theoretical models of reading development provide a limited understanding of children's progress in learning to read because there is little concern over the nature and development of individual differences in reading development. It is argued in this section that examining distinct patterns of analogy use in children's reading skills and acknowledging the possibility of different pathways to reading development might resolve some of the conflict between the underlying principles in current theoretical models of reading.

The first theoretical approach is that proposed by Ehri (1995, 1998) which is developed out of previous traditional stage models of reading (e.g. Frith, 1985; Marsh, Desberg, & Cooper, 1977; Marsh, Friedman, Welch, & Desberg, 1981). In

this framework, Ehri proposed that most beginning reader's use a letter recoding strategy, where the key phonological unit to decode unfamiliar words is the phoneme. In this strategy beginning readers phonologically recode words by translating letters into sounds and then blending the sounds into words. Ehri (1995, 1998) suggested, therefore, that analogy was only available to those readers who had gained experience in letter recoding and who were able to store a complete representation of the rime in memory. Ehri's claim that children's use of analogies in reading develop later after the onset of phonemic awareness, is in keeping with the claims made in earlier stage models of reading development (e.g. Frith, 1985; Marsh *et al.*, 1977; Marsh *et al.*, 1981). Moreover, similar claims about the salience of phonological recoding in early reading development have been expressed in a number of empirical studies (Bruck & Treiman, 1992; Muter, Hulme, Snowling, & Taylor, 1998; Nation & Hulme, 1997; Seymour, Duncan, & Bolik, 1999). For example, the findings of Ehri and Robbins (1992) supported Ehri's approach by showing that the beginning readers needed phonological recoding skills to use analogies during reading. According to Ehri and Robbins, non-readers were not able to read by analogy because they lacked the appropriate knowledge for decoding words into individual phonemes.

However, an alternative characterisation of children's reading development is the interactive analogy model of reading development (Goswami, 1993) and was developed out of an earlier theoretical account of reading proposed by Goswami and Bryant (1990). Unlike Ehri, Goswami (1993) presents an argument that the use of analogy is fundamentally important to beginning reading. According to the interactive analogy model, analogical processes play an important role throughout reading acquisition (even in beginning reading) and that the child's success in using analogy depends on their developing levels of phonological awareness. The model characterises the development and refinement of reasoning skills according to phonological knowledge.

Children's ability to use analogies in early reading is linked to the development of phonological awareness and children's progression in learning to read develops along a path of refined use of lexical analogies. During the early stages of learning to read when children are introduced to single syllable words, they tend to associate spelling sequences with two large phonological units (i.e. onset-rime units) and so the first type of analogy to emerge are those which represent these phonological structures. In contrast to Ehri, Goswami proposes that improvement in children's phonological knowledge precedes the development of an understanding of individual phonemes and graphemes and a more sophisticated level of phonemic representation. This then allows them to make increasingly refined orthographic analogies. According to this account, the development of analogy in reading will therefore be affected by this refinement in phonological awareness (Goswami, 1993). The model proposes that orthographic analysis is founded in phonological skills and that children's phonological knowledge is intimately connected to orthographic development.

The two theoretical approaches offer two different characterisations of children's early reading success. Although Ehri emphasises the importance of letter-sound knowledge and phonemic decoding in initial reading, Goswami emphasises the role of onset and rhyme, which is later followed by an awareness of individual phonemes. Nonetheless, Goswami (1995a, 1999a) pointed out that the reading by analogy approach does not necessarily exclude the teaching of the alphabet or teaching of phoneme knowledge. Therefore, although the empirical support for the interactive analogy model is impressive (see Farrington-Flint, Wood, Canobi, & Faulkner, 2004; Goswami, 1986, 1988, 1990a, 1990b, 1993; Goswami & Mead, 1992; Muter, Snowling, & Taylor, 1994; Nation & Hulme, 1994; Walton, 1995; Walton & Walton, 2002; Walton, Walton, & Felton, 2001; Wood, 1999, 2000, 2002; Wood & Farrington-Flint, 2002) this does not necessarily exclude the importance of alternative routes to learning to read.

An important limitation with both Ehri (1992, 1995) and Goswami's (1993, 1998) current theoretical accounts of reading is that both accounts fail to fully characterise the nature of individual differences in children's development in learning to read. It is reasonable to suggest that both models still assume a single pathway to children's successful early reading development. Whilst Ehri proposes a pathway that develops from grapheme-phoneme correspondences to a later use of orthographic analogy, Goswami (1993) proposes a pathway that develops from an early refinement of orthographic analogy starting from the use of rime correspondences to a later use of analogies based on increasing phonemic structures (see Goswami, 1993). There is, at present, no theoretical account of reading that considers the possibility of identifying multiple pathways to reading achievement. It is argued therefore that some of the conflict between Ehri and Goswami's theoretical accounts can be resolved by acknowledging the possibility of different pathways to reading development.

In order to develop a detailed theoretical account of beginning reading, further research that (a) examines the possibility of identifying individual difference patterns in children's use of analogy in reading and (b) provides a more detailed and accurate measurement of the types of strategies children employ when learning to read, is needed. Examining these issues will provide a stronger basis for evaluating these current theoretical accounts of reading development and in turn may lead to the identification of alternative pathways to reading success (other than those outlined by Ehri and Goswami's accounts). These issues are central to the present research and are therefore discussed in more detail in the following sections.

2.2.2. Experimental Studies of Reading by Analogy

If children's analogical reasoning skills in reading are intimately linked to the proposed sequence of phonological development, as theoretical accounts suggest, then

analogies based on onsets and rimes would be expected to emerge prior to analogies based on single phonemes. There is strong experimental support for the position that children's early use of orthographic analogies within reading is systematically related to their early phonological knowledge (Goswami, 1986, 1988, 1990a, 1990b, 1993; Goswami & Mead, 1992). These studies have all supported the claim that children's expectations about orthography and their orthographic skills are founded in the different kinds of phonological skills they develop and the process of learning to read (see Stuart & Coltheart, 1988).

To provide a suitable methodological framework for the study of analogical reasoning skills in children's reading, Goswami (1986) devised a procedure referred to as the clue word task. This task was designed to assess whether young children had an analogy strategy available to them during the early stages of learning to read. Within this task, the features of conceptually related problems (e.g., bean - mean) are systematically varied to assess children's ability to use these relations as a basis for reading new unfamiliar words. To avoid the child having no basis for making an analogy, children are presented with a clue word, and this clue is decoded for them. The clue word remains visible throughout the procedure allowing the child to refer back to the spelling-sound pattern of the previous word. Each child is then shown a series of target words, some of which share an orthographic overlap with the clue word (e.g., bean - mean) and some of which are controls that share no orthographic overlap with the clue word (e.g., bean - food). Children were presented with only two words at any one time, a clue word and a target word, and were asked to read the target word back to the experimenter. This procedure is designed to test the assumption that if children are sensitive to any orthographic overlap between clue and target words, the mere presence of the clue word should be sufficient to provide a prompt that will allow the child to read orthographically and phonologically related words. Sensitivity to orthographic overlap

between clue words and target words implies that children are making an orthographically based analogy (Goswami, 1999a).

The use of the clue word task provides a framework for examining analogical reasoning skills in early reading. In an early study, Goswami (1986) gave 6, 7 and 8 year-old children a selection of words that were generally difficult for them to read without explicit prompts. Children were presented with a clue word (e.g., beak), which remained in view as they attempted to read a number of target words (e.g., peak, bean). The findings from Goswami's (1986) study led to an important conclusion; namely that children, as young as 6-years-of age, could read significantly more orthographically similar analogous words correctly with the clue-word present, than unrelated control words, demonstrating they were capable of exploiting the orthographic analogy strategy when available to them. Generally, Goswami found that younger readers made significantly fewer analogies than older readers, and suggested that this may be because younger children have smaller reading vocabularies. Her analyses also confirmed that analogies between spellings sequences at the end of words (e.g., beak - leak) were made more frequently by children than analogies between spelling sequences at the beginning of words (e.g., beak - bean). This effect seems to be extremely robust and points to the salience of rime as a phonological and orthographic unit for these young children.

In a series of later experiments, Goswami (1993) examined children's use of vowel analogies in single syllable words in early reading. It is apparent from these studies that as reading develops, analogies are no longer restricted to the level of rime; instead analogies based on phonemes are used. Goswami (1993) revealed that her sample of beginning readers were limited to making analogies at the level of rime (e.g., beak- leak). Children with better reading skills and experience, usually around the age of 6 years 10 months, were able to make spelling-sound correspondences at the level of the rime (e.g., beak - leak), onset-rime (e.g., beak - bean) and vowel (e.g., beak - mean). This

ability to make vowel analogies is related to an awareness of phonemic structures. To provide a theoretical explanation of these findings, Goswami (1993) suggested that orthographic and phonological knowledge continue influencing one another throughout the child's reading development. Moreover, she claimed that children, from a relatively early age, are able to consciously attend to the shared orthographic overlap between the clue words and target words and use this overlap as a basis for reading new words. According to Goswami's approach, the orthographic analysis of written words is founded therefore in children's early phonological skills (Goswami, 1993).

The results from these early investigations have shown that young children, even those with limited reading experience, are able to make analogies between the spelling-sound patterns in words. The fact that this orthographic analogy effect for rime has been replicated many times, using converging techniques (Bowey, Vaughan, & Hansen, 1998; Brown & Deavers, 1999; Ehri & Robbins, 1992; Farrington-Flint *et al.*, 2004; Moustafa, 1995; Muter *et al.*, 1994; Nation, Allen, & Hulme, 2001; Savage & Stuart, 1998; 2001; Walton, 1995; Wood, 1999, 2000, 2002; Wood & Farrington-Flint, 2002), gives considerable support to Goswami's initial claims regarding the salience of orthographic analogies in early reading. The results from these investigations have provided a detailed characterisation of the development of analogical reasoning skills in relation to age and phonological knowledge, which forms the basis of existing theoretical models of reading development (see Goswami, 1993; Goswami & Bryant, 1990).

However, an important methodological weakness inherent in Goswami's experimental studies concerns the extent to which her clue word task increases children's ability to focus on the sound of the clue word rather than the spelling pattern. It has been argued that hearing the pronunciation of the clue word alone is sufficient to facilitate analogical transfer. The findings from a series of more recent studies have since shown that the apparent 'orthographic' analogy effects found in Goswami's own

investigations may be best explained by phonological priming (Bowey *et al.*, 1998; Nation *et al.*, 2001; Roberts & McDougall, 2003; Savage & Stuart, 1998, 2001). The difficulty lies in attempting to establish whether the demonstrated orthographic analogy effects in reading are simply an artefact of phonological priming (see Bowey, 1999; Goswami, 1999c).

Very early on, the possibility of phonological priming as an explanation of orthographic analogy use in beginning reading was rejected. Goswami's (1990a, Experiment 1) initial investigation explicitly examined the possibility that phonological priming could explain orthographic analogy effects in beginning reading by explicitly comparing children's performance on orthographic (e.g., bean - mean) and phonologically (e.g., bean - seen) related words. Children were more accurate in reading items that were orthographically related and thus rejected the phonological priming interpretation. However, more recent investigations suggest that phonological priming is more prominent than Goswami originally proposed (Bowey *et al.*, 1998; Nation *et al.*, 2001; Roberts & McDougall, 2003; Savage & Stuart, 1998, 2001).

In a landmark study, Bowey *et al.* (1998) reinvestigated beginning readers' use of orthographic analogies in word reading to assess the possibility that the entire strength of orthographic rime analogies in word reading could be accounted for by the effects associated with phonological priming. In their second experiment, Bowey and colleagues examined analogical transfer across three conditions; beginning analogy (e.g., beak - beat), vowel analogy (e.g., beak - neat) and rime analogy (e.g., beak - leak). Using a between-subjects design, phonological controls were presented for all word types. In support of earlier findings, Bowey *et al.* report significant increases from pre-test to test analogy scores for beginning analogy, vowel analogy and rime analogies for both first and second-grade children. Further analyses were carried out to investigate the relative size of beginning, middle, and end analogy effects when corrections were

made for phonological priming effects in all three analogy groups. Following adjustments for phonological priming (e.g., test analogy scores minus phonological priming score), only the beginning analogy effect remained significant suggesting that beginning readers' use of rime analogies is not independent of phonological priming effects. This finding is difficult to reconcile within the interactive analogy framework (see Goswami, 1993).

However, there has been debate over the results of this investigation (e.g. Bowey, 1999; Goswami, 1999c; 2001b; Savage, 2001). According to Goswami (1999c), there are a number of important methodological limitations inherent in Bowey et al's design. First, the clue-word task was replaced with a list reading procedure. In contrast to the clue-word procedure in which only two words remain available at any one time, Bowey *et al.* presented children with an analogy booklet containing the complete list of clue and test words. In this booklet, children's were presented with one clue word, followed by a list of 10 test words corresponding to either beginning, vowel or rime analogy. Children's performance was examined using this booklet design within the same experimental session. This meant that each child had to read all 72-test words in the single 15-minute session, which is difficult even for second grade children (i.e., 6-to-7-year olds). The large number of words can influence each other's pronunciation when presented in the same 15-minute session. Second, Goswami argued that there is an increased likelihood of intralist priming effects within Bowey et al's design. Only four vowel phonemes were used to devise the experimental words therefore repeating the same vowel sound could have inflated phonological priming effects. Third, there was strong evidence of unintentional intralist priming effects across conditions. Some of the items included in the 'beginning analogy' and 'middle analogy' booklets were rime analogy words or rime primes used in the other booklets. This is problematic because children would have already been exposed to some of the rhymes and this would artificially inflate performance in these two conditions. After the removal of these unintended

intralist-priming items, it is likely that the high levels of analogical performance found in the beginning and middle conditions would no longer be apparent (see Goswami, 1999c). Further evidence for the phonological priming explanation, however, also comes from recent studies designed to manipulate the nature of the prompt and the target words in the clue word task itself (Nation *et al.*, 2001; Savage & Stuart, 1998, 2001). This research evidence, in addition to Bowey and colleagues, suggests that phonological priming and decoding skills are responsible for the apparent orthographic analogy effect found in previous studies.

However, rather than suggesting that phonological priming may result from the demands of the clue word task, or that phonological priming is a result of an incorrect use of orthographic analogies during reading, it is more likely that children's ability to make analogies based on orthographic and phonological relations, either together or independently, may constitute alternative pathways to reading success. It is likely that these discrepant results presented by Bowey *et al* (1998) and Goswami (1993) can be integrated into a single explanation if research looks at different pathways to reading. It is likely that the continuous debate over phonological priming versus orthographic analogy can be clarified by attempting to characterise different pathways to children's success in reading by analogy.

As well as considering alternative pathways to reading development, it could be argued that further examination of phonological priming effects is needed because it is likely that children's ability to make phonologically based judgements when learning to read may be important in its own right. However, the idea that the children's responsiveness to phonological priming (in the context of the clue word task) is indicative of a level of developing phonological competence has not yet been fully examined. The importance of examining this aspect of children's performance becomes all the more significant if researchers change their approach and analyse the results of

such studies to enable a discussion of individual differences in children's development of different analogy strategies in early reading. It may be the case that the availability of phonological primes in combination with varying degrees of orthographic knowledge may be jointly responsible for these results (see Nation *et al.*, 2001). Looking more specifically at individual difference patterns in children's use of orthographic and phonological relations in reading may, therefore, help to clarify these issues and provide a more developed understanding of reading development generally. It is perhaps more likely to suggest that children may be using a combination of orthographic and phonological correspondences to read target items. It is also likely that the discrepant findings of previous studies may indicate that some children use an orthographic analogy strategy whilst others use a phonological analogy strategy.

In summary, a closer examination of relations between orthographic analogy and phonological priming is needed in order to clarify some of the recent debates within the literature. It is likely that beginning readers vary in their ability to use analogies in early reading, in their levels of phonological priming, and in the relations between these two patterns of variation, but this needs to be examined explicitly. It is also argued the best way to achieve this is to consider individual differences in children's analogical reasoning skills in reading and to consider alternative pathways to development. This issue is discussed in detail in the next section.

2.3. Individual Differences in Analogical Reasoning

The purpose of this section is to demonstrate the importance of studying individual differences in children's analogical reasoning skills in early reading. It is argued that there is a tendency for researchers to examine variation across different age groups and different analogy conditions without any consideration for the possible variation within these specific groups. Inadequate attention is given to diversity in children's

reasoning and, as a result, there is a lack of concern for the possibility of identifying different patterns of analogy skills and little concern for acknowledging alternative pathways to reading development (see also Siegler, 1996). It is also claimed that previous research is weakened by averaging data over individual children rather than considering patterns of individual differences in their reasoning skills. It is also argued that research is needed to provide a more detailed examination of the possible strategies children may be using when approaching the task of reading, or decoding, unfamiliar words. It is claimed, therefore, that a more detailed examination of individual differences and new methodologies concerned with measures of individual strategy choice is needed. This, in turn, will help to provide a more accurate characterisation of early reading development.

2.3.1. Age Related Changes in Analogy

Reading researchers have provided a detailed characterisation of the possible developmental changes in children's use of orthographic analogies in early reading (Goswami, 1993, 1999a; Goswami & Bryant, 1990). These accounts have indicated that ability to use rime analogies precedes the ability to make analogies based on onset-vowels and vowels alone (see Goswami, 1993). However, there is a strong tendency for researchers to examine variation across different age groups and across different analogy conditions without any consideration of the variation within these age groups. Focussing on age-related changes in reasoning, however, may provide an incomplete understanding of analogical reasoning in this domain.

Previous experimental studies have relied on comparisons using group averages to assess analogy skills in early reading (e.g. Goswami, 1986, 1988, 1990a, 1990b, 1993; Goswami & Mead, 1992; Muter *et al.*, 1994; Wood, 1999, 2000, 2002; Wood & Farrington-Flint, 2002). Relying on averaged data across conditions, however, fails to provide sufficient detail concerning variation in children's performance and individual

children's level of competence on each of the different conditions in the clue word task. It is reasonable to suggest that not all beginning readers will perform at the same level or in the same way when reading analogy-based word items and there is likely to be high levels of variation in children's accuracy scores. Although some children may demonstrate increased levels of analogising in reading, other children may make significantly fewer analogies overall within early reading. Furthermore, whilst some beginning readers may show elevated levels of using rime-based analogies, others may demonstrate some ability to make analogies based on other spelling-sound units. Therefore simply comparing accuracy scores across individuals is problematic and leads to an incomplete understanding of analogy development since not all children of the same age will be explicitly using their knowledge of relations to solve analogies in the same way. A central argument presented in this thesis, therefore, is the need to consider variation within groups and the possibility of identifying different patterns of early reasoning ability.

In her earliest study, Goswami (1986) specifically set out to examine the possibility that children's use of analogies in reading were intimately linked to their knowledge of spelling-sound correspondences. In the study, to examine the salience of analogical transfer in reading, comparisons according to differences in children's scores across different analogy conditions were performed. On the basis of their word reading proficiency, children were divided into three different age groups corresponding to kindergarten, first-grade and second-grade and possible differences in analogy scores were examined according to these age groups. The results from the study were consistent in indicating an age-related developmental trend in children's ability to make analogies in word reading: 5 year-old non-readers were only accurate in making orthographic rime analogies whilst the first and second grade children were found to be accurate in making onset-vowel analogies and analogies based on shared vowel diagraphs, which coincided with an increase in phonemic awareness.

Further support for an age-related progression in analogical development can also be found in Goswami (1993). Three experiments examined children's analogical performance making contrasts between progressively more complex single-syllable words and progressively older readers (5, 6, and 7 year-olds). Analogical transfer was examined with target words corresponding to onset-vowel correspondence (e.g., bug - bud), rime correspondence (e.g., bug - rug) and vowel only correspondence (e.g., bug - cup). In Experiment 1, using single syllable consonant-vowel-consonant (CVC) words, 5 year-old beginning readers showed a significant analogy effect for rime units but no evidence of analogies based on vowels only or shared onset-vowel units. In Experiment 2, using more complex consonant-vowel-vowel-consonant (CVVC) words, 6-year olds showed a more complex pattern of transfer with evidence of making analogies on shared rime units, onset-vowel units and vowels only. These results are indicative of developing phonemic awareness. In Experiment 3, 7 year-olds demonstrated the same pattern of analogical reasoning as in Study 2. However, although children showed more accurate levels of performance in reading the shared rime units and onset-vowel units, no significant transfer was found for vowels only.

These examples from Goswami's (1986, 1988, 1993) early investigations provide an illustration of how researchers often make broad systematic comparisons across different age groups to examine analogical reasoning in word reading. The examples provided above clearly illustrate how there is a tendency to overlook individual children's performance in reading. There are, nonetheless, theoretical claims regarding individual differences in the way in which young children read by analogy. For instance, in a recent review, Goswami (1999a) has claimed that the ability to make reading analogies depends on individual differences in children's phonological awareness. However, it is noteworthy that very often theoretical claims regarding the importance of individual differences in children's analogical reasoning skills are put forward but these claims are

based on the use of analytical techniques (regression analyses) that do not allow for the detailed identification of individual differences. There are two studies that are often cited within the reading literature as providing support for individual differences in children's analogy (Goswami, 1990b; Goswami & Mead, 1992).

In an early study, Goswami (1990b) examined which type of phonological skills was most strongly related to making analogies in early reading. Multiple regression analyses revealed that a measure of rhyme awareness was the strongest concurrent predictor of rime analogies in reading. The relationship between rhyming ability and orthographic rime analogies accounted for 28% of the variance in the regression model, and an additional 20% after the contribution of vocabulary and phoneme deletion skills had been taken into account. In a further study, Goswami and Mead (1992) using the same regression analytical approach found evidence that onset-rhyme measures were related to rime analogies, and phonemic awareness (e.g., consonant deletion measures) were related to onset-vowel analogies in early word reading. According to Goswami (1999a) these two prominent studies provide a clear illustration that "individual differences in rime analogies (beak - peak) were related to individual differences in rhyme awareness whereas individual differences in 'beginning' analogies (beak - bean) were related to individual differences in phoneme awareness" (p. 223). However, the empirical evidence does not necessarily support this claim.

Although these studies by Goswami (1990b) and Goswami and Mead (1992) illustrate how the development of children's orthographic analogies in word reading is associated with their developing phonological knowledge of sounds there were no attempts to look at different characteristic patterns or profiles of analogical reasoning and how these profiles varied according to their phonological skills. The reliance on regression analysis is problematic as there may be different subgroups of children who show distinctive profiles of reasoning ability. Therefore, in order to address

claims of individual differences among children fully, an additional analytic approach is required to identify different profiles of reasoning skills, such as cluster analysis (see Lyon, 1983; Lyon & Watson, 1981). This would allow researchers to identify different patterns of responses, or subgroups of children, according to the efficiency they demonstrate in using analogical reasoning strategies in reading. It is then possible to compare standardised measures of phonological awareness against these different subgroups or clusters to address whether phonological knowledge can accurately predict patterns of individual differences in the use of analogy in beginning reading.

There is some empirical support to the suggestion that looking for profiles in reading skills is profitable. For example, researchers interested in studying the heterogeneity of dyslexia tend to examine or identify different groups of children based on their cognitive performance across range of tests using cluster analytic techniques (e.g., Fletcher *et al.*, 1997; Lyon, 1983, 1985; Lyon, Stewart, & Freedman, 1982; Stanovich, Siegel, Gottardo, Chiappe, & Sidhu, 1997). This has proved successful in developing a more detailed understanding of dyslexia. For instance, rather than accepting a single classification model for dyslexia, Lyon and colleagues (Lyon, 1983; Lyon *et al.*, 1982; Lyon & Watson, 1981), examined the possibility of identifying subtypes across a range of different cognitive, linguistic and perceptual skills in children with dyslexia. These batteries of tests were administered to 100 learning disabled readers and 50 typically developing children between 11 and 12 years (matched for reading age). Data was analysed using cluster analysis and different subtypes were identified each of which were characterised by different patterns in linguistic and perceptual deficits. Overall, the classification model led to the identification of six distinct profiles. Four of these subtypes revealed unitary linguistic difficulties or a combination of visual-memory and linguistic difficulties together (Clusters 1, 2, 3, & 5). Another subtype revealed low scores on visual memory

and visual motor task (Cluster 4), and the final subtype showed adequate performance on all measures (Cluster 6).

A particular advantage of identifying sub groups or profiles, however, is the possibility of considering different variations in children's reading abilities and examining possible intervention programs more effectively. To validate the efficiency in using this classification procedure to identify different subgroups, Lyon et al (Lyon, 1983; Lyon *et al.*, 1982; Lyon & Watson, 1981) externally validated the six-subtype cluster solution through application of an educational intervention study. (In this phase of the study, 5 children were taken from each of the corresponding six-clusters and matched on their ability to read single words and their age, gender and IQ). After brief intervention using a synthetic phonics program, only those children with visual memory or visual motor difficulties (Cluster 4) and those who performed adequately across all measures (Cluster 6) showed any significant gains in reading achievement overall. The studies by Lyon and colleagues raise our awareness of the potential benefits of identifying alternative subtypes of reading difficulties in children. The use of cluster analytic techniques is useful in evaluating alternative forms of reading-based interventions for children with specific forms of reading difficulties.

Despite the significance of cluster analytic techniques for examining different profiles or subtypes of reading disability, there has been a lack of research attention given to different profiles of reading skills in normal reading development. However, as already noted, looking for distinct and meaningful patterns in children's analogy performance using indices of solution time and accuracy will lead to a more detailed characterisation of children's development in learning to read. It is likely, similar to those studies concerned with dyslexia, that different profiles or subtypes may emerge based on children's ability to use orthographic and phonological relations in beginning reading. The identification of qualitatively different patterns of reasoning skills might

suggest that children do not progress through a single profile or in a single sequence as advocated in current theoretical models. Instead such patterns of reading skills may indicate that children find their own routes to reading that are not currently emphasised in these earlier theoretical accounts.

In summary, it is argued that cluster analytic techniques that look for characteristic patterns in children's reasoning scores are particularly worthwhile since this approach is useful in identifying different profiles of performance or knowledge (see also Canobi, 2004; Canobi *et al.*, 1998, 2003; Siegler, 1988a for examples in addition). The present research was concerned primarily with applying this individual differences approach to children's reading and their ability to apply knowledge of orthographic and phonological relations to solve analogical problems on reading analogy tasks. It is likely that examining children's ability to use analogical reasoning skills on an individual level (rather than relying on group averages) will lead to a more detailed understanding of reading development, and a closer consideration of variation in children's reading abilities.

2.3.2. Variability in Children's Strategy Choices

The consideration of variability in children's individual strategy choice is another area that has considerable potential for making a contribution to our understanding of reading development. It is likely that averaging data over participants may help to create an impression that young children use analogy strategies much more than they actually do. It is argued, therefore, that a more detailed assessment of the different types of strategies children are using on reading analogy tasks is needed. Because children have a range of different strategies available to them as they approach the task of learning to read, including retrieval, sounding out and blending together individual phonemes as well as the ability to make analogies between related words, it is likely that analogical reasoning strategies are not used consistently during beginning reading. However,

researchers have tended to use group averaged performance measures (e.g., accuracy) to make claims about children's strategy use without measuring strategies independently. This is related to an issue that is raised with regard to the consideration of different analytic techniques, techniques that consider individual performance scores not just group averages.

A related point that is addressed in the research program is developing more sensitive measures of children's strategy choice. This has two main advantages in both providing information on individual processes that is not available from performance scores (like accuracy) and providing the basis for a more stringent test of competence than achieved in previous research. Measures of strategy choice are clearly needed in the light of claims that in other contexts, such as addition, most children are known to use a wide repertoire of strategies, and that they do not always use the most advanced strategy available to them (see Siegler, 1996; Siegler & Campbell, 1989; Siegler & Jenkins, 1989). For instance, variability in children's strategy choice is evident across a variety of contexts including reading and spelling (Rittle Johnson & Siegler, 1999; Siegler, 1988a), as well as addition and subtraction (Siegler, 1987, 1989; Siegler & Shrager, 1984). It seems reasonable to suppose, therefore, that this might be true with respect to children's use of analogies in the context of reading.

While averaging over strategies has seemed so successful that this has provided the foundations for several well defined and influential theoretical models of early reading (see Frith, 1985; Goswami, 1993; Goswami & Bryant, 1990; Marsh *et al.*, 1981) at present we are still unsure whether children are strategically applying their knowledge of analogy as a basis for reading target words on the clue word task. It may be that the use of multiple strategies may be responsible for children's reading success. Reading development provides an ideal domain for illustrating the effects of averaging over strategies and the potential benefits of examining each individual strategy

separately. It is argued that a detailed assessment of the different types of strategies children are using on reading analogy tasks is needed and this can be achieved by using retrospective self-reports of children's strategy choices (see Siegler, 1987, 1989).

Although whilst children's use of verbal self-reports have been largely ignored within the developmental reading literature, the use of individual self-reports might offer further characterisation of the skills children are using when they approach the task of learning to read and whether the application of such skills is consistent across trials and across tasks. The use of verbal reports can thereby provide a clearer understanding of the types of strategies children are using to read unfamiliar words on reading analogy tasks.

The need to examine verbal self-reports of strategies is underscored by the possibility that the use of multiple strategies may be, in part, responsible for some of the analogy effects found in previous studies. There is consistent evidence that children do use a wide repertoire of strategies in domains other than reading and this raises our awareness of the possible consequences of not providing a measure of strategy choice in reading (Siegler, 1987, 1989). It is argued that children may not be purposely using analogy strategies to read all related words on the clue word task, but may use a wide repertoire of strategies. There is some evidence that children show high levels of variability in their choice of strategies in reading and spelling from a recent study by Rittle-Johnson and Siegler (1999). In their investigation, they found evidence of high levels of variability in strategy choices in children's spelling using retrospective verbal reports. In terms of their individual spelling scores, they found that 30 first-grade children often reported using multiple strategies to spell unfamiliar words ranging from 2 to 5 strategies overall, 70% using two or more strategies in the first-grade and 95% used two or more strategies in the second-grade. A wide repertoire of strategies was reported including, although not exclusively, retrieval, sounding-out, retrieval/sound-out, drawing analogies and relying on previously taught spelling rules. Therefore, spelling is not characterised by

the use of any one single strategy. This illustrates the importance of considering strategy choices more carefully in relation to children's analogical reasoning performance in reading.

Strategy choices may vary from person to person and from problem to problem. Furthermore, within other areas such as the context of simple addition, research has shown that children of a single age often use a wide variety of strategies to solve any one problem, and even the same child presented with the same problem on two separate occasions are found to use different strategies (Siegler, 1987, 1989). Indeed, according to these studies, there are differences in the speed and accuracy of different strategies, the processing demands of these strategies and the range of problems to which strategies can be applied (see Goldman, Mertz, & Pellegrino, 1989; Rittle Johnson & Siegler, 1999; Siegler, 1987, 1988a, 1989; Siegler & Stern, 1998).

In summary, although there is support for Goswami's original claim regarding the importance of orthographic analogies in early reading, research into the development of analogy use in reading has some important limitations that need to be addressed. Namely, further research identifying distinct patterns of analogy skills especially with regard to the speed and accuracy of children's analogy performance across children and across trials, is needed. There is also a possibility that children are using a wide repertoire of strategies and the possibility that children may not be strategically or consistently applying an analogy strategy to read new words. It is argued that addressing these limitations in previous research will lead to a more detailed theoretical account of the progress children make in learning to read (Goswami, 1993).

2.4. Chapter Summary

In this chapter, it has been claimed that analogical reasoning plays an important role in the development of children's reading skills, particularly within the early

stages of learning to read. It was also suggested that children's ability to reason analogically within reading is linked to the development of phonological awareness and children's progression in learning to read develops along a path of refined use of analogies. However, it has been argued that more attention to individual differences in reasoning skills is needed.

It was claimed that although research has contributed a detailed characterisation of age-related changes in analogy skills in reading, further investigation is required to consider variation among children. However, in previous investigations, within-group variability is often incorrectly treated as error variance. Furthermore, there is a need for researchers to treat variability between children and across tasks seriously. It was therefore argued that in order to develop a detailed consideration of individual differences, important methodological and analytical limitations need to be addressed, specifically: (a) research that focuses inappropriately on averaged accuracy scores alone; (b) the use of analytic approaches that pay insufficient attention to variation within and between individuals, and (c) little concern for examining possible variability in children's repertoire of strategies in early reading. It was claimed that many of these difficulties might be addressed by examining individual differences in children's analogical reasoning skills. Furthermore, it was suggested that studying individual differences in analogical reasoning skills in this domain might provide important information concerning alternative pathways to reading success. This, in turn, might provide a better foundation for addressing theoretical debates surrounding phonological priming and thereby lead to a more detailed theoretical account of reading.

Finally, it was argued that further detailed examination of children's use of various strategies in reading is needed. The importance of looking closely at strategy choices is underscored by claims that young children may not be strategically applying analogies to read unfamiliar words. It is suggested that retrospective self-reports will

provide a more detailed assessment of variability in strategy choices within reading and establish whether children are strategically applying their knowledge of analogy in the clue word analogy task. Assessing strategic variability on the reading analogy tasks will also provide a more detailed understanding of individual differences.

To situate these findings within a wider developmental context, and to consider the potential importance of analogies beyond the context of reading, the use of analogical reasoning skills in other contexts needs further consideration. For this reason, in Chapter 3, children's ability to make analogies in the context of simple addition, and the ways in which their reasoning ability is related to individual differences in domain knowledge, is considered. This will provide a basis for later considering possible commonalities in children's ability to reason analogically across the two domains of reading and addition.

CHAPTER THREE

ANALOGICAL REASONING IN CHILDREN'S ADDITION

3. Introduction

If young children can make analogies in early reading, it seems plausible to suggest that children will be able to make analogies in other domains such as the domain of mathematics. Although there is support for the importance of analogical reasoning in relation to children's mathematics (English, 1997b; English & Halford, 1995), previous research is limited by focussing on analogical reasoning skills in older children or adults or investigating the contribution of analogical reasoning to mathematical problem solving, such as algebra or understanding of proportions (e.g. Alexander, White, & Daugherty, 1997; English, 1997a, 1998; English & Sharry, 1996; Gholson, Smither, Buhrman, Duncan, & Pierce, 1997; Spinillo & Bryant, 1991, 1999). Considerably less research, however, has been directed towards children's use of analogies between addition problems. Researchers have tended to ignore the potential for theories of analogical development to contribute to, or provide a framework for, understanding children's early addition development. The purpose of this chapter, therefore, is to examine children's use of analogies within the context of addition.

To provide a detailed background to this discussion, previous research concerning the development of children's understanding of addition principles is presented. The possibility that addition principles can be used as a basis for analogical reasoning is then evaluated. It is argued that our present understanding of analogy in addition is weakened by conceptual tasks that (a) focus on judgements, justifications and explanations of conceptually related problems, (b) rely on the child's ability to spontaneously notice

shared relations between problems, and (c) provide an indirect measure of analogical reasoning. It is also argued that these methodological limitations can be overcome by devising new research methodologies for measuring analogical transfer in addition, akin to the analogy tasks used within the context of reading. It is argued that further clarification of the possible links between domain-specific problem solving and analogies in addition is required. Looking for distinct patterns in children's use of analogy and their problem solving will lead to a more detailed understanding of individual differences in the context of addition.

3.1. Domain Knowledge in Addition

The goal of this section is to demonstrate how exploring aspects of children's understanding relating to commutativity, associativity and additive composition may lead to important discoveries concerning analogical development in addition. The relations that a child needs to have represented in order to make analogies between addition problems are conceptual relations that operate on the basis of mathematical properties of whole number addition. Before examining the possibility that analogical reasoning is important in children's addition, the following sections will provide a working definition of these concepts and explore the development of addition concepts in young children.

3.1.1. Knowledge of Formal Addition Principles

In the present research, formal addition principles are used for examining children's use of analogies in early addition. There are strong claims that the mathematical properties of whole number addition are important for providing useful insights into children's emerging conceptual knowledge (Gelman & Gallistel, 1978). It is therefore reasonable to suggest that the properties of whole number addition will provide a useful insight into children's analogical reasoning skills. Three formal addition principles that

are relevant to children's conceptual understanding within this domain (see Canobi *et al.*, 1998, 2002, 2003). The first, commutativity, is the principle that problems containing the same sets in a different order have the same answer, $(a + b = b + a)$. The second, additive composition, is the principle that larger number sets are made up of smaller sets $(a + b = a + b + c)$. This principle is based on the claim that most natural numbers are composed by addition and can therefore be additively decomposed in various ways. The third, associativity, is the principle that problems in which sets are composed can be decomposed and recombined in various ways and still have the same answer, $(a + b) + c = a + (b + c)$. The properties of whole number addition, specifically commutativity, associativity and additive composition are an important aspect of children's mathematical knowledge and form the basis of many key theories of development (Gelman & Gallistel, 1978; Piaget, 1952).

One advantage of using formal addition principles for examining the development of analogies within addition is that these principles lend themselves well to an analogical reasoning framework. There are claims that children construct an analogous understanding of relations between problems by noticing when addends are reordered and decomposed and recombined (Canobi *et al.*, 1998, 2003). This ability to construct an understanding of commutativity, associativity and additive composition is likely to underpin the ability to reason about conceptually related addition problems. A second advantage of using formal addition principles is that some principles (e.g., associativity) are more difficult for children to grasp than others (e.g., commutativity). Indeed, given that these principles vary in complexity, it is likely that exploring the sequence in which children learn about addition concepts will provide a more detailed understanding of the development of analogical skills in the context of addition. Some forms of analogy may develop earlier than others. A third advantage of using formal addition principles as a framework for examining analogies within the context of addition is the

proposed link between knowledge of addition principles and early problem solving skills (Canobi *et al.*, 1998, 2003; Cowan & Renton, 1996; Martins-Mourao & Cowan, 1998; Putnam, deBettencourt, & Leinhardt, 1990). This link between principle based knowledge and problem solving can be used as a basis for examining the possible relationship between patterns of analogical reasoning in addition and individual differences in domain specific problem solving skills.

3.1.2. Developmental Progression of Addition Principles

Since understanding addition principles is all about recognising relations between problems, it is likely that exploring the sequence in which children learn about these principles, specifically, commutativity, associativity and additive composition, will provide important insights into analogical reasoning skills in addition. However, although there are current suggestions that children construct mental representations of some principles before others, the research evidence is inconclusive. It remains to be established whether an understanding of commutativity and associativity are independent and learned in a particular sequence (Canobi *et al.*, 1998, 2002, 2003) or whether the two emerge together out of an understanding of additive composition (Resnick, 1992, 1994). This issue is particularly important if the research is making the claim that the development of addition concepts is intimately related to the development of analogical reasoning, and therefore requires further investigation.

There is evidence in the mathematics literature that suggests that young children develop a relatively early understanding of addition principles. For example, Sophian, Harley and Vong (1997), Cowan and Renton (1996) and Canobi *et al* (2002) show how preschoolers develop a strong grasp of relations based on the principle of commutativity. There is also increasing evidence that young children also show some success in recognising relations between addition problems based on associativity and additive

composition (Canobi *et al.*, 2002; Langford, 1984).

Resnick (1992, 1994) has argued, however, that children might not consider commutativity and associativity as separate entities, rather, their understanding of these principles develops out of, and is dependent on, a more general understanding of additive composition. This suggestion was based on the notion, later emphasised by Putnam *et al.*, that “applying this part whole schema permits children to think of numbers as compositions of other numbers, enabling them to solve mathematical problems that could not otherwise be solved” (p. 246).

However, there is strong empirical support that commutativity and associativity develop independently. In an early study by Langford (1981) 30, 5 to 6 year-olds were examined on their ability to judge related problems presented in concrete terms. Over a period of 24 months, children’s knowledge of commutativity and associativity were assessed at 4 intervals, 6 months apart. Children were prompted with questions and their verbal explanations were coded. Conceptual knowledge was tested the same way, which involved combining and decomposing physical objects (boxes of beans) and recording verbal explanations. Langford’s findings were taken as support that young children develop an understanding analogous to commutativity prior to associativity. However, the extent to which these findings can be generalised can be questioned since the associativity task employed in the study failed to assess associativity by the decomposing and reordering of addends, instead children’s re-ordering of problems was taken as evidence of associativity (According to the formal definition of the principle, associativity should be assessed in terms of decomposing and recombining problems in a given set in order to solve related problems). Thus, Langford’s failure to examine children’s ability to decompose and recombine sets, suggests that his results may not demonstrate an understanding of associativity; instead it provides knowledge analogous to additive

composition so his claims regarding children's understanding of the associativity principle is limited.

More recently, there is growing support for the claim that children's knowledge of the commutativity principle develops prior to knowledge of associativity (e.g. Canobi *et al.*, 1998, 2002, 2003; Close & Murtagh, 1986; Langford, 1981). Close and Murtagh (1986) examined young children's ability to solve conceptually related problems analogous to the principles of commutativity and associativity. Each problem was presented as number sentences and children were required to complete the problem by placing the correct integer into the mathematical problem (e.g., $14 - 6 = ?$ or $3 + (? + 8) = 13$). Measuring the accuracy of their responses assessed children's performance. The results revealed a striking comparison between commutativity and associativity-based problems, and showed that the former was easier to solve than the latter. This led to the conclusion that commutativity-based knowledge may develop prior to that of associativity-based knowledge. However, Close and Murtagh make explicit claims regarding children's conceptual understanding without measuring this directly. In their study, children's conceptual understanding of commutativity and associativity was based solely on measures of problem solving accuracy, which could be argued is problematic.

Canobi and colleagues have also demonstrated that children appear to be far more successful at recognising and explaining commutativity-based problems than they are at explaining concepts related to additive composition and associativity. Canobi *et al.* (1998) found that through the identification of different knowledge profiles (using cluster analysis), children developed an understanding that sets could be reordered before understanding that sets could be decomposed and recombined. Moreover, this advantage for problem relationships based on commutativity over those based on associativity and additive composition was found using various contexts (concrete, abstract and symbolic problems) (see Canobi *et al.*, 2002, 2003)

It is suggested that the ability to make inferences or predictions about the relationship between conceptually related problems in addition, therefore, forms the basis of analogical reasoning in this domain. The use of analogy in the context of simple addition depends on the child's knowledge of addition concepts, such as commutativity, associativity and additive composition and their ability to use their knowledge of these principles to solve conceptually related problems. As illustrated in the previous section, young children do develop a relatively early understanding of these three addition concepts and there is at least some partial evidence to suggest that there is a natural progression of addition knowledge developing from an awareness of commutativity to a later awareness of associativity and additive composition (Canobi, 2004; Canobi *et al.*, 1998, 2002, 2003; Close & Murtagh, 1986; Langford, 1981).

If there is a developmental progression in children's understanding of addition concepts, then it is likely that children's age will be related to their knowledge of addition concepts. However, this evidence also remains inconclusive. Although there is considerable evidence that children's addition problem solving skills improve with age, such as that older children solve problems more quickly and accurately and use more advanced strategies than younger children (Ashcraft & Fierman, 1982; Boulton-Lewis & Tait, 1994; Canobi *et al.*, 2002; Carpenter & Moser, 1984; Geary & Brown, 1991; Geary, Brown, & Samaranayake, 1991; Goldman, Mertz, & Pellegrino, 1989; Siegler, 1987, 1989), less is known about age-related improvements in conceptual knowledge. Although Canobi *et al.* (2002, 2003) found school children's addition problem solving improves with age they found that knowledge of addition principles did not improve with age. However, in contrast, Langford (1981) and Bermejo and Rodriguez (1993) found evidence for age effects in children's understanding of relations based on addition principles such as commutativity and associativity. Therefore, the possibility of a

developmental trend in children's conceptual knowledge of addition principles still remains unclear.

In the present research, it is proposed that children's analogical reasoning in addition is intimately linked to their conceptual understanding of whole number addition. Furthermore, it is anticipated that young children are able to make inferences or predictions about problems based on this knowledge of addition. If this claim is correct, then it is likely that analogies based on commutativity (e.g., $2 + 6$ and $6 + 2$) will emerge prior to analogies based on knowledge analogous to additive composition or associativity (e.g., $2 + 3 + 5$ and $2 + 8$). However, although there is some suggestion that young children can recognise and solve related problems within addition (see Gelman & Gallistel, 1978) the conceptual tasks that are currently available seem to provide an indirect or, at best, implicit measure of analogical reasoning ability. A more explicit framework is required to identify whether any of the currently used tasks provide a reliable measure of analogical reasoning in addition. An examination of some of the current conceptual measures is presented in the following section.

3.2. Measuring Analogical Skills in Addition

There are surprisingly few studies exploring analogies between addition problems, although the context of addition lends itself well to analogical reasoning. This section will identify what conceptual tasks are currently available within the context of addition and which of these tasks will provide the best measurement of analogical reasoning skill. It is argued that previous measures of conceptual understanding are limited because they only manage to provide an indirect and implicit measure of analogical reasoning ability. In particular, previous judgments tasks have been concerned with children's ability to provide judgements and justifications for problem relations rather than their ability to solve conceptually related problems in addition. Previous problem solving

tasks have used a strict criterion of assessing children's ability to spontaneously notice problem relations, which may be too difficult for young children. It is argued, therefore, that alternative methodologies are needed to explore analogy explicitly rather than embedded within the current conceptual measures.

3.2.1. Methodological Critique of Judgment Tasks

The first type of task that is used to measure conceptual knowledge is the judgment task (see Canobi *et al.*, 1998, 2002; Langford, 1981; Putnam *et al.*, 1990). In judgment tasks, young children are asked to recognise and explain conceptual relations between addition problems when these problems are related by principles such as commutativity, associativity and additive composition. However, such judgment tasks provide only an implicit measure of analogical reasoning skill since they are concerned with children's ability to recognise, explain and justify problem relations. It does not, however, examine whether children are using addition principles explicitly as a basis for solving addition problems by analogy.

Putnam *et al* (1990) used a judgement task to examine young children's understanding of additive composition. In his study, children in third-grade were asked to provide judgements and justifications for the use of decomposition strategies modelled by puppets. Children were not required to use any computation procedures to work out the answer to part-solved problems, instead they were asked to judge the effectiveness of using specific strategies. Children were found to accurately justify the use of decomposition strategies and this, according to Putnam *et al.*, provided a measure of their understanding of additive composition.

Canobi *et al* (1998) used a similar approach to assess children's ability to judge, explain and justify the different ways related problems could be solved when modelled by a puppet. Children were asked to comment on whether they needed to calculate the

answer using counters or whether the preceding problem could assist in working out the answer to a new problem. Children's ability to judge and justify principle-based relationships was used as evidence that young children could demonstrate some conceptual understanding analogous to commutativity, associativity and additive composition (see also Canobi *et al.*, 2003). Although such tasks may provide a strong measure of conceptual knowledge they do not directly address analogical reasoning ability since children's ability to use the preceding problem as a basis for solving unfamiliar problems is not explicit. That is, examining children's ability to provide judgements and justifications for related problems does provide a measure of their knowledge of specific concepts, but they do not provide a direct measure of analogical skills in the domain.

In summary, although these judgment tasks initially appear to be tapping into children's analogical reasoning skills, tasks of this nature tend to provide only an indirect or at best, an implicit measure of reasoning ability since no analogical transfer is involved. There is little evidence that children are explicitly using the previous problem as a basis for making the analogy between the two related addition problems and as a result they may be relying on other strategies (e.g., counting or decomposition) to make their judgements other than using analogical relations.

3.2.2. Methodological Critique of Problem Solving Tasks

Another way of assessing conceptual knowledge in addition is to examine children's ability to solve conceptually related problems using a procedural task (e.g. Canobi *et al.*, 1998, 2002). In problem solving tasks children are required to calculate the answers to simple addition problems. Children are given the answer to an initial problem, which provides them with a basis to make the analogy (e.g., $4 + 6$ and $6 + 4$). Although the previous problem remains in view, no suggestion to refer to previous problem is given to

the child. Instead, children are required to spontaneously notice relations between a problem that they had previously solved and the next problem they were given. Children are not explicitly instructed that the previous problem could assist them to solve a subsequent addition problem (see Canobi *et al.*, 1998, 2002). Assessing children's knowledge in this way offers a very strict criterion of understanding and is perhaps too difficult a procedure for a child to demonstrate his or her understanding of conceptual principles. Noticing the similarity between two problems and then use this similarity as a basis for solving similar problems may be cognitively too complex for 5-to-6 year old children. Such children may be capable of making analogies between related problems if they are explicitly told that the previous problem can be used as a basis for working out the answer to the new problem, but fail to do so in the current problem solving tasks.

Initially, Canobi *et al.*'s (1998) problem solving task seems to provide a fairly direct measure of analogical reasoning skill as it appears to be concerned with examining children's ability to use the previous addition problem as a basis for solving related problems. However, on closer examination, it could be argued that this problem solving measure is likely to underestimate children's analogical reasoning performance for three main reasons. First, the task is concerned with assessing children's ability to recognise similar relationships between problems rather than applying knowledge to solve problems explicitly. Children are required to spontaneously notice relations between a problem that they had previously solved and the next problem they were given and they were not instructed that the clue problem could assist them (Canobi *et al.*, 1998). The emphasis here is on their ability to spontaneously notice principle-based relationships between related problems. Second, the problem solving task is a very strict measure of procedural skill and the cognitive demands of the task may be too difficult for young children. There were also very few related problems (14 out of 46) included in this conceptual measure which makes the conceptual aspect of the task limited since it provides fewer

opportunities for children to spontaneously notice principle-based relationships between related problems. Including a low number of actual related problems also adds to the level of difficulty of the task. Assessing children's propensity to notice relationships between problems based on mathematical principles provides little information concerning their ability to apply their knowledge of relations to solve problems analogically. Third, the instructions given to the children are ambiguous and indirect. Because there is no explicit prompt available to them, children may not have realised that they were allowed to use the initial problem as a basis for making an analogy. This may account for why children were often found to be using different strategies for solving related problems, including retrieval, decomposition and counting procedures (see Canobi, 2004; Canobi *et al.*, 1998). Some children might have preferred working out the answer than showing a spontaneous understanding of relations between problems whilst others may have considered not calculating the answer but using conceptual knowledge evidence of cheating (Baroody, Ginsburg, & Waxman, 1983; Cowan & Renton, 1996). Failing to give children specific instructions to use the initial problem as a strategy for solving related problems may also have prompted them to calculate the answer rather than use their conceptual knowledge specifically.

In summary, it is clear that both the conceptual judgement task and problem solving task are both unsuccessful in providing an unambiguous, direct measure of analogical reasoning skill in children's addition. Instead, these tasks provide an implicit measure of analogical reasoning skill alone because children will not necessarily look for relationships unless instructed to do so. What is needed is an approach that examines whether children can use such relationships to solve addition problems when prompted. Therefore, to fully examine the role of analogy in addition, it is argued that a more refined and explicit methodological approach is required.

3.2.3. Developing a Suitable Analogy Framework

The purpose of this review has been to argue that a more explicit and direct measure of reasoning is required than those that are currently available within addition and to, furthermore, develop a stronger theoretical rationale to situate analogical reasoning within the addition literature. It is necessary to study relational reasoning more explicitly by looking at children's approaches to analogical problems and to identify the extent to which children are successfully applying their knowledge of relations (commutativity and additive composition) as a basis for solving related addition problems. Framing conceptual tasks so that the analogical component is measured in a more explicit and direct way, rather than embedded within the conceptual measures, which is typically used in previous studies (Baroody, 1987a; Baroody & Gannon, 1984; Baroody *et al.*, 1983; Canobi *et al.*, 1998, 2002) should provide a more precise account of analogical performance in addition.

In devising an appropriate task for exploring analogical transfer in addition, there are strong benefits of using examples of analogical tasks used in other domains. For example, as discussed in Chapter 2, there is already an explicit measure of analogical transfer that uses a clue word approach to assess reading skills (see Goswami, 1993). This method was originally devised to examine whether beginning readers have an analogy strategy available to them in word reading (see Chapter 2, Section 2.2.2). However in relation to the context of addition, this kind of task is not currently available. It is clear that a more explicit methodology, which lends itself to looking for relational similarities between addition problems, is needed. The clue word task used in the reading domain has been shown to be a very useful measure of assessing analogical transfer with word items. This provides an explicit measure of analogical transfer in reading that can be adapted to assess children's ability to recognise relational similarities between addition problems by replacing words with addition problems.

Many of the limitations with previous measures of conceptual understanding in addition (as outlined in section 3.2 above) can be overcome by using a modified version of Goswami's (1993) clue word task. For example, in order to make an analogy in the context of addition, a number of requirements need to be addressed. First, the child must be able to infer the answer to one problem with reference to a conceptually related problem, when these problems are related by principles such as commutativity, associativity or additive composition (e.g., commutativity, $2 + 3$ and $3 + 2$). Second, rather than simply relying on the child's ability to spontaneously notice relationships between problems, children need to be told that the initial prompt might assist them in solving other problems. Providing children with an initial problem and presenting them with the answer to this problem should avoid the child having no basis for making the analogy. Third, this clue should also remain in view during the trial to allow each child to refer back to the initial problem. These three task features will lead to a more systematic and direct measure of children's use of analogy in addition. Given that each of these requirements are already included in Goswami's clue word task, the task seems an ideal framework for the current research program.

Importantly, an addition analogy task that is structurally similar to the clue word task in reading will provide the opportunity to make more systematic and detailed comparisons of children's analogy performance across the two contexts of reading and addition together. Such comparisons are important because the ways in which children use analogical reasoning skills across different domains has not yet been examined empirically. This could lead to a number of important theoretical and educational contributions regarding the ways in which young children can be taught to recognise analogies and how this could contribute to their reasoning skills across a variety of different contexts or domains. Perhaps examining different profiles in children's analogical reasoning skills in addition will present a framework for making

cross-domain comparisons between children's reasoning abilities in reading and mathematics.

There is some evidence that strong cross-domain relationships can be found between children's reading and mathematics as illustrated in a study by Siegler (1988a). In his study, Siegler (1988a) examined individual difference patterns in the strategy choices of 36 first grade children. The children performed three tasks corresponding to addition, subtraction and word reading. For comparability across tasks, the different strategies that children reported were reduced into one of two categories: either retrieval or back-up strategies (e.g., counting or decomposition for addition and subtraction and sounding-out or analogy for reading). To explore whether different children's performance on each of the three tasks fell into characteristic patterns, cluster analysis was performed using percent correct, mean reaction time and frequency of the use of correct back-up strategies for all three tasks. Cluster analysis revealed high levels of consistency across the different tasks. The clustering algorithm classified children into one of three groups, referred to by Siegler as good students, not-so-good students, and perfectionists. Good students demonstrated a good knowledge of problems, used retrieval on most problems and were relatively accurate whether they used retrieval or back-up strategies across all three tasks. The not-so-good students demonstrated less knowledge of problems, were less accurate irrespective of whether they used retrieval or back-up strategies and tended to rely on backup strategies more often than the good students. The third group, perfectionists, were children who demonstrated good knowledge of problems and they were highly accurate across the three tasks but used retrieval as little as the not-so-good students. Moreover, four months after the experiment children were given standardised achievement mathematics task, which validated the results from the cluster analysis. Perfectionists and good student's scores on standardised achievement tests were particularly high and both groups outperformed the not-so-good students. The identification of

individual differences in children's strategy choices seems to highlight strong similarities in children's accuracy performance across the reading and mathematics domains.

The study demonstrates how useful it is to identify different patterns of responses, or subgroups of children, according to the efficiency they demonstrate in solving problems across the two domains of mathematics and reading. This type of analytic technique is better than using regression analyses because we are no longer averaging performance data (accuracy) across groups of children but instead concentrating on each individual child's score in solving problems in both reading and mathematics. Indeed, examining different profiles of performance according to children's individual strategy choices across tasks provides information on individual processes that is not available from performance scores (accuracy) (see Siegler, 1987, 1989). It is argued, therefore, that cluster analytic techniques can provide the most comprehensive account of individual differences in children's performance across different domains of knowledge.

3.3. Analogical Reasoning and Addition Problem Solving

The purpose of this section is to argue that further research is needed to examine the extent to which domain-specific problem solving skills contribute to children's use of analogies in addition. It is claimed that knowledge of addition concepts is associated with changes in problem solving skills (Canobi *et al.*, 1998, 2002, 2003; Cowan & Renton, 1996) and that advances in conceptual knowledge can often lead to advances in procedural skills. However, because measures of principles do not explicitly address children's ability to make analogies, the extent to which children's domain-specific problem solving skills relate to their ability to reason analogically in addition is unknown. It is argued, therefore, that research needs to assess whether addition problem solving skills are related to analogical reasoning within addition and, if so, whether advances in analogical reasoning skills are related to advances in problem solving

sophistication. A way of exploring relations between patterns of analogy and problem solving skills is to consider patterns of individual differences.

3.3.1. Conceptual Understanding and Problem Solving

There are strong systematic relations between children's conceptual understanding of mathematical principles and their addition problem solving (Canobi, 2004; Canobi *et al.*, 1998, 2002, 2003; Cowan, 2003; Cowan & Renton, 1996). Whilst it is claimed that mathematical concepts guide and constrain problem solving (Gelman & Gallistel, 1978; Resnick, 1986, 1992) the precise way in which it this might occur requires further research attention. Often methodological and interpretive problems limit the generality of research findings because research often focuses on a single conceptual-procedural link (e.g., commutativity and counting-on) rather than examining the relationship between various concepts and children's repertoires of problem solving procedures. Nonetheless, tasks assessing knowledge of addition principles are important not only because they have led to important discoveries concerning conceptual-procedural links (Canobi, 2004; Canobi *et al.*, 1998, 2003) but they also provide a useful insight into children's ability to reason by analogy.

Because addition problem solving is related to traditional conceptual knowledge tasks, which in turn provides an indirect measure of reasoning skill (see Canobi *et al.*, 1998, 2003) domain-specific problem solving skills are also likely to be related to children's use of analogies in the context of addition. However, given that addition researchers have tended not to provide a direct measure of analogical skills, the question remains whether problem solving is related to a more explicit domain-specific measure of analogical reasoning skill. To address this question, it is important to establish whether similar concept-procedure relations emerge when the research looks at commutativity and additive composition in terms of analogy (Canobi, 2004; Canobi *et al.*, 1998, 2003).

There is some suggestion that children's ability to use analogies based on addition principles, such as commutativity, might be related to their problem solving skills. There have been claims that the use of advanced counting principles (e.g., counting on from the largest addend) is related to children's knowledge of commutativity (Groen & Resnick, 1977; Martins-Mourao & Cowan, 1998; Resnick, 1983; Resnick & Ford, 1981). In their early research, Groen and Resnick, (1977) suggested that economical counting procedures may be indicative of children's understanding of the commutativity principle in their study with 4 year-olds. Children were asked to solve a series of single digit addition problems using wooden blocks. Children's performance was examined both with and without access to these blocks. Using measures of overt responses and individual solution times, Groen and Resnick, found that many children were capable of using the min procedure rather than the counting procedure that was previously taught to them. This study was taken as strong support in favour that the min procedure demonstrates an understanding of commutativity.

Nevertheless, there are a number of findings inconsistent with this suggestion. There are claims that children are capable of using the min procedure without an appropriate understanding of the commutativity principle (Baroody, 1987b; Baroody & Gannon, 1984; Baroody & Ginsburg, 1986). For instance, in a study of 36 5 to 6 year-olds, Baroody and Gannon (1984) examined the relationship between children's understanding of the commutativity principle and their use of counting strategies to solve a series of simple single-digit addition problems. They also examined commutativity in relation to economical addition strategies, such as, counting-all and counting-on from the larger addend. In the study, children were presented with an addition task and two commutativity tasks over three experimental sessions. On the first commutativity task children were required to provide a quick response as to whether the two problems presented side-by-side would equal the same number, or whether the result

would be different. The children in this task were not required to solve the problems by computation. In the second commutativity task, children's problem solving performance was examined directly by asking children to solve simple addition problems (e.g., $6 + 7$). Afterwards, children were presented with commuted problem and asked whether the sum would be the same and to explain their decision. In terms of measurement, children who responded quickly and accurately on the addition problems were credited with an understanding of commutativity. The findings revealed that whilst children managed to use economical counting strategies, for example, counting-on from the larger addend strategy, they did not necessarily reveal an understanding of commutativity. Thus, whilst commutativity may play a role in the use of economical counting strategies, it is entirely possible that children can use new strategies when solving mathematical problems without having a formal understanding of the commutativity principle. This finding would suggest that children's ability to use analogies based on commutativity is independent to problem solving skills.

Nevertheless, there are limitations to Baroody and Gannon's study that question the generalisability of these findings. Cowan and Renton (1996) have suggested that Baroody and Gannon (1984) might have underestimated children's understanding of the commutativity principle for the following reasons. Firstly, they used a measure of speed as an indication of children's understanding of the commutativity principle which may have been misguided since measures of both speed and accuracy tends to ignore what specific strategies children are using whilst solving addition problems (Siegler, 1987, 1988a). Secondly, children may have performed poorly on explaining the principle of commutativity in the judgement task due to a general difficulty in verbalising their strategies or a lack of confidence in explaining their procedures.

In response to these limitations, Cowan and Renton (1996) attempted to examine children's understanding of commutativity by using a more stringent

measure. In their study children were asked to judge whether two problems were similar when these problems were related by the mathematical principle of commutativity. This study also provided problems in three conditions, either in symbolic, concrete or abstract form. Cowan and Renton (1996) concluded from their study that there was strong support that commutativity preceded strategy use on addition problem solving tasks. This finding has been strengthened by further studies that have illustrated how order-indifferent counting strategies may reflect an understanding of commutativity (Bermejo & Rodriguez, 1993; Groen & Resnick, 1977; Resnick, 1992, 1994). Although, on closer inspection of the results, the findings presented by Baroody and Gannon (1984) and Cowan and Renton's (1996) investigations are remarkably similar. The difference is that whilst Baroody adopts the questionable strategy of arguing that commutativity is not related to advanced counting procedures based on one or two rare cases, Cowan and Renton attribute such cases to measurement error.

Such disagreements that question whether children's ability to use order-indifferent counting procedures genuinely reflects an understanding of commutativity are intriguing. Whilst Cowan and Renton (1996) and Groen and Resnick (1977) suggest that children's use of order-indifference reflects a conceptual understanding of commutativity, alternative suggestions have been presented. For example, Baroody and colleagues (Baroody, 1987b; Baroody & Gannon, 1984; Baroody & Ginsburg, 1986) argue that children's ability to use order-indifference in their counting strategies may not reflect an understanding of commutativity, rather it may be a reflection of children's desire to use a more economical way of counting.

Given the current evidence concerning commutativity and counting-procedures, and the recent debates, it is likely that individual differences can, in part, account for these discrepancies in research findings. For example, it is likely that whilst some children may discover concepts before showing any evidence of advanced counting

procedures (in line with Cowan & Renton, 1996; Groen & Resnick, 1977), for other children, using advanced counting principles may lead to the discovery of commutativity (in line with Baroody & Gannon, 1984; Baroody *et al.*, 1983). Therefore, a closer consideration of individual differences between children's conceptual and their procedural skills is needed.

Another area that has received recent interest is that of decomposition strategies and knowledge of associativity (Baroody & Standifer, 1992; Christensen & Cooper, 1991; Cowan, 2003; Martins-Mourao & Cowan, 1998; Putnam *et al.*, 1990). It is reasonable to suggest, therefore, that children's use of decomposition strategies may also be related to their use of analogies in addition. It is assumed that knowledge analogous to additive composition or associativity is implicit in the use of decomposition procedures within addition. This would suggest that analogies based on additive composition would be related to children's problem solving skills. Putnam *et al.* (1990) examined children's understanding of relationships and their ability to explain and judge decomposition strategies in third grade. Children were shown a series of addition and subtraction problems modelled by puppets and asked to evaluate and justify different decomposition procedures (e.g., solving $6 + 7$ by using knowledge that $6 + 6$ equals 12 and simply adding one more to 12 to arrive at the correct answer which is 13). Putnam *et al.* (1990) found that just under half of the third-grade children were able to make explicit justifications for the use of decomposition procedures in solving addition and subtraction problems (although children found the use of decomposition to subtraction problems more difficult). The study is impressive because it demonstrates how children can use their knowledge of conceptual relations to solve decomposition problems within addition and subtraction and also reveals that many young children may have an implicit understanding of additive composition (i.e. that numbers can be additively composed of smaller numbers). However, there are also a number of important

methodological limitations. First, the method of asking children to judge and evaluate the effectiveness of using decomposition strategies provides only an implicit account of their conceptual knowledge of additive composition. Asking children to judge partially solved decomposition problems requires a different skill than using knowledge of additive composition to spontaneously solve decomposition problems independently by themselves (i.e., analogy). Second, Putnam *et al.* (1990) focus solely on the relation between additive composition and decomposition and ignore the possibility that other procedures, such as retrieval or counting strategies may contribute to children's understanding of additive composition type knowledge.

It is also likely, however, that through the use of decomposition strategies in problem solving, children learn about additive composition and associativity. For example, in a study by Christensen and Cooper (1991) decomposition strategies were assessed in a short-term training study with 40 second-grade children. In the pre-test session none of the second-graders used decomposition strategies to solve addition problems. Children were then given 15 minutes of instruction each day for 12 weeks. Half of the group were explicitly taught to use decomposition strategies whilst the remaining half solved simple addition and subtraction problems with no specific instruction or guidance. Children showed equivalent gains in using decomposition strategies across both groups. Those children who did not receive any formal tuition on using decomposition strategies used them as frequently as children in the experimental training group. Given that decomposition strategies are a fairly direct application of concepts, findings support the possibility that experience with solving addition problems can eventually lead children to discover new addition concepts or relations.

Overall, the links between addition problem solving and conceptual knowledge is not well defined. This is due to important methodological limitations. Often conceptual development is often inferred from changes in problem solving skill rather

than assessed directly or independently (Bisanz & Lefevre, 1992; Carpenter, 1986; Giaquinto, 1995). For instance, although older children tend to solve addition problems more quickly and accurately than younger children, using more sophisticated strategies, such as order-indifferent, decomposition and retrieval strategies (Ashcraft & Fierman, 1982; Geary, Brown, & Samaranayake, 1991; Goldman *et al.*, 1989), this does not qualify them to have conceptual understanding of addition principles. Making inferences about conceptual development on the basis of such data is problematic because children tend to use a range of problem solving strategies, and those capable of using more advanced strategies do not always do so (Siegler, 1996; Siegler & Shipley, 1995). Also, with a few exceptions (Baroody *et al.*, 1983; Canobi, 2004; Canobi *et al.*, 1998, 2002, 2003; Langford, 1981), children's knowledge of each addition principle has been examined separately rather than exploring interrelations among different addition principles. Given this tendency for research to focus on isolated concepts alone, it is increasingly difficult to identify the links between specific concepts and procedures (c.f. Canobi *et al.*, 2003). These have implications for the types of conclusions the research can make about conceptual understanding in addition and, due to such interpretive problems, a more detailed consideration of concepts and procedures is needed.

It appears that the links between addition problem solving and conceptual knowledge are not well defined in the addition literature. However, aside from these methodological limitations, the extent to which addition problem solving skills relate to analogical reasoning skills in addition is currently unknown. It is reasonable to suggest that because conceptual knowledge is related to children's problem solving skills, then these problem solving procedures might also be related to children's use of analogies within the domain. However, the specific links between different types of analogy and different problem solving procedures has not been tested empirically. To avoid difficulties with focussing on a single conceptual-procedural link, it is recommended that the best way

of exploring relations between analogy and domain-specific problem solving is to compare children's analogical reasoning skills against different patterns of problem solving. This issue is discussed in more detail in the next section.

3.3.2. Patterns of Problem Solving Skills

There have been some studies that have addressed individual differences in children's addition (Canobi *et al.*, 1998, 2002, 2003; Dowker, 1998; Siegler, 1988a; Siegler & Campbell, 1989), but very few studies have looked at different patterns in procedural skills. The study of individual difference patterns in children's mathematical abilities may prove informative because children often use a wide variety of strategies to solve any one addition problem, and even the same child presented with the same problem on two separate occasions are found to use different procedures (Siegler, 1987, 1988b). Therefore, characterising children's problem solving according to their repertoire of procedures and the speed and accuracy associated with these different procedures is profitable.

Research has shown that there are large variations in children's problem solving skills in the context of addition (Siegler, 1987, 1989). For instance, young children use a wide repertoire of strategies for solving addition problems (Canobi *et al.*, 1998, 2003; Siegler, 1989). Furthermore, whilst retrieval and decomposition procedures are associated with quick and accurate responses, the use of counting procedures is generally laborious and less efficient overall (Ashcraft & Fierman, 1982; Boulton-Lewis & Tait, 1994; Canobi *et al.*, 2002; Carpenter & Moser, 1984; Geary & Brown, 1991; Geary *et al.*, 1991; Goldman *et al.*, 1989; Siegler, 1987, 1989). This demonstrates the relative importance of studying patterns of variation in children's problem solving according to their repertoire of procedures and the speed and accuracy associated with these procedures.

However, unlike children's reading, there is already a strong tradition of using verbal

self-reports to measure procedural skills within the context of addition. In many studies of addition problem solving discrete measures of speed and accuracy are recorded and analysed after the presentation of every problem. This focus on procedural outcomes has provided an extensive and detailed contribution of children's addition problem solving capabilities within the domain (Baroody & Gannon, 1984; Baroody *et al.*, 1983; Carpenter & Moser, 1982, 1984; Geary & Brown, 1991; Geary *et al.*, 1991; Goldman *et al.*, 1989; Siegler, 1987; 1989). For example, Siegler, (1987) found that children of the same age use a wide repertoire of procedures to solve addition problems including counting procedures (count-all/count-on), retrieval, and decomposition and as children gain experience in solving problems, they tend to use more sophisticated and more flexible procedures. Older children tend to report using retrieval and decomposition more frequently than younger children. They also tend to use advanced counting procedures, such as counting on from the problem term unlike younger children who use less sophisticated counting procedures. With problem solving experience, children become faster and more accurate in solving addition problems. They tend to rely less on simple, laborious procedures, such as count-all, which involves counting out all problem terms starting from 1, and generate new procedures, such as counting-on from the largest of the two problem terms. Following counting procedures and increases in experience, children use more adaptive and efficient problem solving procedures, including decomposition (using a related problem to solve a related problem) and retrieval (knowing the answer). Converging support for this proposed developmental trend in procedural skills is found within the addition literature (e.g., Carpenter & Moser, 1984; Goldman *et al.*, 1989; Groen & Resnick, 1977; Siegler, 1987, 1989; Siegler & Jenkins, 1989).

However, only recently has this data been used to examine different developmental patterns in children's problem solving skills (see Canobi *et al.*, 1998; 2003). The reason for not carefully examining individual differences is a tendency to average

solution time data across individuals and to treat within-group variation as the same as error variance. With a few exceptions (Canobi, 2004; Canobi *et al.*, 2003), researchers have generally ignored the possibility of identifying meaningful profiles of problem solving skills. Canobi *et al.* (2003) demonstrated the potential benefits of using cluster analytic approaches to classifying patterns of problem solving competence in addition. In this study, profiles of problem solving skills were strongly related to conceptual understanding of addition principles. Problem-solving profiles revealed qualitative differences in children's repertoires of addition procedures as well as differences in their problem-solving accuracy. The profiles indicated that one group of children had not yet learned to use addition procedures that would lead to correct answers. Another group tended to rely on solely counting-all procedures to compute answers. A third group used a combination of counting strategies (including counting on, and counting all) and retrieval. The most sophisticated group, however, used a combination of mental arithmetic strategies, decomposition, and counting-on procedures. The profiles demonstrate useful differences in the type, accuracy, and number of strategies children use to solve addition problems, which may indicate different pathways to problem solving achievements. Furthermore, children who demonstrate an understanding of concepts in addition also tend to use sophisticated patterns of problem solving (Canobi, 2004; Canobi *et al.*, 1998).

Although there are many advantages to examining different patterns of problem solving skills in children's addition, it is important to develop this suggestion further by examining links between analogical reasoning and different patterns of problem solving abilities. An issue addressed in the present research is the possibility that the sophistication of children's problem solving skills might be related to the extent to which they use analogical reasoning strategies to solve related problems in the context of addition.

3.4. Chapter Summary

The purpose of this chapter was to demonstrate the need to further consider the role of analogical reasoning skills in the context of simple addition. It was argued that children demonstrate an early understanding of addition principles and this conceptual understanding of addition is likely to form the basis for making analogies within the domain. As well as outlining how addition principles can be used to assess analogical reasoning ability in the context of addition, a methodological critique of conceptual tasks has revealed that there is currently no precise or explicit measure of analogical reasoning skill within the addition domain. It was argued in this chapter that existing conceptual tasks are weakened by a limited focus on measuring children's judgements, justifications and explanations of conceptually related problems, and an over reliance on young children's ability to spontaneously notice shared relations between problems. These tasks seem to provide, at best, an indirect assessment of analogical reasoning skills. It is argued, therefore, that many of the methodological limitations can be overcome by developing an analogical reasoning task akin to the clue word measure used in the reading domain.

Another important contribution is examining relations between analogical reasoning and specific problem solving skills. It was argued that this is needed to fully understand the development of analogical reasoning skills within addition. Although research has shown links between addition concepts and problem solving skills (Canobi *et al.*, 1998, 2002; Cowan & Renton, 1996), the ways in which this relates to analogical reasoning is unclear. That is, because addition researchers have tended not to provide direct measure of analogical skills, it is unclear whether the sophistication of children's problem solving is related to explicit measures of analogical reasoning. It is also argued that in order to avoid the limitations found in previous research with focussing on a single conceptual procedural link, a more useful approach to explore relations between analogy and domain-specific problem solving is to compare children's use of analogy

against patterns of problem solving. This will provide a more complete understanding of children's cognitive development in addition.

CHAPTER FOUR

RESEARCH AGENDA

4. Introduction

In the preceding chapters of this thesis, it was argued that a closer examination of the development of analogical reasoning skills in children's reading and addition is needed. It was also argued that there is a need to examine individual differences more carefully in the context of reading and addition. In particular, it was claimed that a focus on individual differences is likely to lead to a greater understanding of conceptual development within each of these contexts and may lead to the identification of alternative pathways to reading and addition development. A more detailed consideration of individual differences may have implications for cognitive models of reading and addition.

In this thesis, five specific research questions are addressed. These research questions emerged from the literature review presented in the preceding chapters.

First, are there meaningful patterns of individual differences in children's use of orthographic and phonological relations to make analogies in early reading? Second, is the ability to make analogies important to children's knowledge of addition, and furthermore, what is the relationship between children's use of analogy within addition and their domain-specific problem solving skills? Third, to what extent do more traditional forms of analogical reasoning skills contribute to children's ability to make analogies in the context of reading and addition? Fourth, how consistent are children in applying their knowledge of relations to solve analogical problems within each context? Fifth, are there any similarities in the way in which young children use analogies in early reading and addition and do distinct patterns of reasoning skills emerge when classifying children's responses across tasks? In the following sections, the theory and

research relevant to the five research questions is summarised and working hypotheses about the results of the studies are outlined. This will illustrate how the current research program addresses the five main research questions set out in the thesis.

4.1. Patterns of Analogy in Reading

The first research question concerns whether distinct patterns of individual differences in children's analogical reasoning in early reading can be identified. In Chapter 2, it was argued that one of the most important limitations with previous research in the reading domain has been a tendency to focus solely on group average accuracy scores across conditions or age groups rather than examining individual children's reasoning skills. Despite the significance of her findings, Goswami's (1986, 1988, 1990a, 1990b, 1993; Goswami & Mead, 1992) examination of orthographic analogies in reading has relied solely on comparisons across conditions using averaged data. It was argued in Chapter 2 that looking for characteristic patterns in the speed and accuracy with which children solve different analogy problems in reading will add to our understanding of children's development in learning to read. Furthermore, it was claimed that examining patterns in children's responses to solving analogical problems in reading would allow us to examine the possibility that analogies based on phonological sounds are an important pathway to reading that may be independent to orthographic analogies.

It has already been argued that there is inadequate attention paid to diversity in children's reasoning abilities and this has led researchers away from important developmental questions about how children choose between different forms of reasoning skills and how these choices change in line with domain knowledge (see Siegler, 1996). It is argued, therefore, that examining different patterns in children's analogical reasoning abilities will lead to the possibility of different pathways to development in early reading. Identifying different patterns of analogical reasoning might also contribute to

existing theoretical models of reading development (Goswami, 1993; Goswami & Bryant, 1990).

In order to address some of the limitations of previous research, the present research was designed to classify children's patterns of responses to solving orthographic and phonological analogy problems on the clue word task using cluster analysis. Cluster analysis presents an ideal framework for identifying characteristic patterns in children's reasoning skills (Siegler, 1996). In the present research, Study 1 was designed to explore analogy in reading by looking for differences in the patterns of knowledge displayed by individual children or subgroups of children using cluster analysis. Study 2 was designed to extend the findings of Study 1 by examining individual difference patterns using the speed and accuracy of children's word reading across the different analogy conditions. It was expected that characteristic patterns of analogy skills would emerge that reflect children's ability to make analogies based on orthographic and phonological relations in reading. It was also anticipated that the possible identification of distinct patterns of analogy would reflect the possibility of finding variation in children's reading success.

4.2. Analogies in Addition and their Relation to Problem Solving

The second research question concerns the salience of analogical reasoning in the context of simple addition and the relationship between children's ability to reason analogically in addition and their problem solving sophistication. It was claimed in Chapter 3, that formal principles of addition provide a useful basis for examining analogical reasoning within the domain. There are claims that children construct an early understanding of problem relations by noticing when addends are reordered and decomposed and recombined (Canobi *et al.*, 1998, 2003). The research extends this idea further by examining whether children are able to make analogies based on particular problems that are based on principle-based relationships. It was claimed,

however, that there is currently no explicit measure of analogical reasoning in addition and that new methodologies are required to assess children's analogical ability based on their understanding of conceptual relations between problems based on principles such as commutativity and additive composition. Given that previous research has failed to examine analogical reasoning within addition explicitly, the links between analogies and addition problem solving require further consideration.

As well as examining the salience of analogies in children's addition, it was argued in Chapter 3 that further research is needed that examines the relationship between children's analogical reasoning and their addition problem solving. Research has suggested that there is a strong systematic relation between children's conceptual understanding of addition principles and their addition problem solving (Canobi *et al.*, 1998, 2002, 2003; Cowan, 2003; Cowan & Renton, 1996). In particular, it has been claimed that children's use of advanced counting procedures, such as counting-on or order-indifference procedures, is linked to an understanding of commutativity (Canobi, 2004; Canobi *et al.*, 1998, 2003; Cowan & Renton, 1996; Groen & Resnick, 1977; Resnick & Ford, 1981). Further, there are claims that children's ability to use decomposition strategies to solve unrelated problems is linked to an understanding of principles such as additive composition and associativity (Canobi *et al.*, 1998, 2003; Christensen & Cooper, 1991; Putnam *et al.*, 1990). However, despite this evidence, the precise way in which problem solving procedures relate to analogical reasoning skills within the domain are currently unknown and require additional research.

Accordingly, in Study 3, the salience of analogies within addition was examined using a methodology akin to the clue word task used in the reading domain (Goswami, 1986, 1988, 1990a, 1993). In Study 3, children's reasoning about relations in addition was examined explicitly by looking at children's approaches to analogical problems and identifying the extent to which they are applying their knowledge of addition

principles (e.g., commutativity and additive composition) as a basis for solving conceptually related problems. Furthermore, the relationship between children's use of analogies within addition and their patterns of domain-specific problem solving was examined. It was expected that children would demonstrate a preference for making analogies based on commutativity than additive composition principles given previous claims that children's understanding of commutativity develops prior to an understanding of additive composition (Canobi, 2004; Canobi *et al.*, 1998, 2003; Close & Murtagh, 1986; Langford, 1981). It was also expected that the ease with which children report using analogies within addition would be associated with their domain-specific problem solving skills (e.g., self-reports of counting-all, counting-on, retrieval and decomposition to solve unrelated addition problems).

4.3. The Contribution of Traditional Analogical Reasoning Skills

The third research question concerns whether children's ability to use analogies in reading and addition is related solely to their domain knowledge or whether this kind of reasoning is based on the development of their analogical reasoning abilities more generally. As outlined in Chapters 2 and 3, previous research in both reading and addition has suggested that children's reasoning about relations depends on their understanding of domain relevant principles. Implicit within this claim is the suggestion that a domain-specific approach is appropriate to studying children's early development in early reading and addition. However, as noted in Chapter 1, less attention is paid to the possibility that children's ability to reason about relations in reading and addition is likely to reflect analogical reasoning skills in general.

As argued in Chapter 1, it is important to examine whether children's ability to use analogical reasoning skills in reading and addition reflect a more basic and general capacity to look for and analyse relations between problems that can be

applied within a variety of tasks across domains or alternatively whether children's ability to reason about domain-specific relations is embedded within their domain-specific skills and concepts and not related to other forms of analogical reasoning skills. The current research was designed to examine the extent to which children's analogical reasoning skills (outside the context of reading and addition) could contribute to analogical reasoning skills within the two domains. Accordingly, in Study 2, the relationship between children's ability to use analogies in reading in the context of a reading task and their performance on traditional forms of analogical reasoning skills was examined (based on causal, thematic and visual relations). It was expected that children's performance on these traditional reasoning tasks would be positively related to their ability to solve analogical problems that are embedded within the context of reading. Similarly, in Study 3, the relationship between addition analogies and traditional analogical reasoning skills was examined. As with Study 2, it was expected that children's performance on traditional reasoning tasks would be related to their ability to solve analogical problems in addition.

4.4. Children's Consistency in Using Analogies

The fourth research question concerns whether there is any consistency in children's use of analogies in early reading and addition or whether children report using different strategies for solving analogical problems across the two domains. As argued in Chapter 2, in the context of reading, research into analogical reasoning have tended to concentrate solely on using accuracy scores rather than using verbal self-reports of strategy choices to assess analogy performance directly. In contrast, in the context of addition, researchers have examined verbal self-reports of strategies children use to solve addition problems (e.g. Siegler, 1987, 1988a, 1989; Siegler & Shrager, 1984), however, this is often at the

expense of any detailed examination of children's use of analogical reasoning strategies.

It was argued in Chapter 2 that assessments of verbal self-reports can provide a more detailed understanding about whether children are strategically applying analogy as a decoding strategy in early reading and to characterise the extent to which they use alternative strategies (e.g., retrieval, sounding-out). It is important to consider the possibility that more than one individual strategy may be responsible for children's performance on reading measures such as the clue word task. The possibility that children use a variety of strategies is likely to be reflected in the differences in the speed and accuracy of their individual performance. The same argument can be applied to children's addition in terms of the consistency with which young children use analogy strategies to solve related addition problems and the extent to which they rely on counting procedures, decomposition, and retrieval is likely to be related to the speed and accuracy of individual performance. The present research acknowledged the need to examine analogy performance using more detailed measurement techniques, such as the speed and accuracy associated with children's individual self-reports.

In Studies 3 and 4 measures of verbal self-reports were used to assess the consistency with which children use analogies to solve analogical problems in both reading and addition. After the presentation of each problem, the speed and accuracy associated with children's self-reported strategy was recorded and analysed. On the basis of previous research (Canobi *et al.*, 1998, 2003; Siegler, 1987, 1989), it was expected that children would report using a wide repertoire of strategy use in addition to the use of analogy for solving analogical problems in both reading and addition and that there will be differences in the speed and accuracy depending on which strategy they reported using on a particular trial. It was anticipated that asking children to give self-reports would provide a more detailed and accurate assessment of whether or not children are explicitly using

analogical reasoning strategies within and across the two domains of knowledge.

4.5. Individual Differences in Analogy Skills across Domains

The fifth research question concerns whether there are any links or similarities in children's approach to solving analogical problems in early reading and addition. As argued in Chapter 1, despite theoretical suggestions that children's reasoning depends closely on their knowledge of appropriate domain concepts (Gelman & Brenneman, 1994; Gelman & Gallistel, 1978; Gelman & Greeno, 1989), other researchers argue that young children's knowledge of relations can facilitate reasoning across different contexts or domains (see Gelman & Wellman, 1998). Given the suggestion that analogical reasoning skills may operate on a domain general level, it is important to assess whether children's ability to use analogies in reading is similar to their use of analogies within addition and whether distinct patterns of analogy skills emerge based on children's performance across the two educational domains when examined together. Exploring similarities in children's reading and addition is important because this examination may help provide a more detailed theoretical account of analogical reasoning and shed light on its relationship to cognitive development.

Whereas the previous research question was concerned with examining whether children demonstrate any consistency in their use of analogy strategies in reading and addition, the present research question was concerned with examining whether distinct patterns of strategy choice could be identified for individual children when performance across the two domains was looked at together. Moreover, if distinct profiles emerge this will lead to a better understanding about whether children show any similarities in their approach to solving analogical problems across the two domains together. That is, the present research proposed to explore analogy in both reading and addition by looking for differences in the patterns of knowledge displayed by individual children or

subgroups of children across trials. Cluster analytic techniques were employed because these techniques have the potential to identify different patterns of responses, or subgroups of children, according to the efficiency they demonstrate in solving conceptually related problems across the two domains (see Siegler, 1988a). It was expected that the ways in which young children approach analogical problems across the two domains will be similar and that individual differences in strategy choices will emerge when examining children's performance in reading and addition together.

Accordingly, in Study 4, the relationship between children's analogical reasoning in reading and addition was examined in two ways. First, using measures of reported analogy use, regression analyses examined the extent to which children's ability to reason analogically in one domain could predict their ability to reason analogically in the other domain. Examining concurrent predictors of analogical reasoning in both reading and addition is important for examining the possibility of a domain general analogical component underlying the two areas of knowledge. Second, patterns of self-reported strategy choices were compared across reading and addition using cluster analysis. As claimed in Chapter 1, systematically comparing patterns of strategy use on the different analogy tasks will establish whether there are any similarities in the way children approach analogical problems in the two contexts of reading and addition.

4.6. Chapter Summary

In this chapter it has been argued that there is a need for further empirical research to develop a more precise and detailed understanding of analogy within reading and addition. In particular, it is argued that research needs to (a) characterise individual differences in children's use of analogies within reading more accurately using cluster analytic techniques, (b) examine the salience of analogies in the context of simple addition and how these are related to domain-specific problem solving skills,

(c) examine the relationship between domain-specific forms of analogy (reading and addition) and the contribution of other traditional forms of analogical reasoning skills (d) to examine the consistency with which children use analogies in reading and addition using retrospective verbal reports (e) and to examine individual difference patterns in children's reasoning abilities across the two domains using these measures of verbal self-reports of strategies.

In the present research, these five questions were addressed in four studies. In Study 1, individual differences in children's use of orthographic and phonological relations in early word reading were examined using cluster analytic techniques. This was designed to identify different patterns of responses, or subgroups of children, according to the efficiency they demonstrate in using relations to read unfamiliar words in the context of reading. In Study 2, the findings of Study 1 were extended by an examination of the possible relationship between these patterns of reading analogy, children's phonological knowledge and their traditional analogical reasoning skills. In Study 3, an exploration of the salience of analogical reasoning in children's addition was examined. This was designed to examine the ways in which children could use their understanding of addition principles (e.g., commutativity and additive composition) to solve analogous problems and to investigate the relationship between addition analogies, domain-specific problem solving and traditional analogical reasoning skills. In Study 4, the identification of similarities in children's reasoning skills in reading and addition was examined by looking for individual differences in children's strategy choices across the two domains together. These four studies are now presented in Chapters 5, 6, 7 and 8.

CHAPTER FIVE

STUDY 1: PATTERNS OF ANALOGY IN BEGINNING READING

5. Introduction

The purpose of Study 1 was to explore the possibility of identifying individual differences in children's use of analogies in beginning reading. As mentioned in Chapter 2, it has been proposed that analogical reasoning skills play an important role in the development of early reading skills (c.f. Goswami, 1986, 1988, 1993; Goswami & Mead, 1992). However the possibility of identifying individual differences among children of the same age has not been explored. There is a tendency for previous research to average data across children of the same age and across different experimental conditions rather than considering individual differences. The central goal of Study 1 was to examine the possibility of identifying individual differences in children's use of orthographic and phonological relations in early reading. Another goal of the study was to address some of the recent methodological concerns regarding the reliability of the clue word task as a measure of analogical skills in reading. Examining the reliability of the clue word task is particularly important because this task is used throughout the research program to assess reading analogy (i.e., Studies 1, 2 and 4).

It was suggested in Chapter 2, that previous investigations reveal a linear trend in analogical reasoning skills whereby 5 year-old beginning readers are more accurate in making orthographic rime analogies whilst 6 year-olds tend to be accurate on many more types of analogies including rime analogies, beginning analogies and analogies based on shared vowel diagraphs, which appears to coincide with an increase in phonemic awareness (Goswami, 1993). Within group variation in these age groups (5 year-olds vs.

6 year-olds), however, is not often considered. Rather the prevailing practice has been to compare between group variations in mean scores. However, as argued in Chapter 2, it is entirely possible that some children may find their own routes to reading competence based on their general cognitive abilities and their level of domain relevant knowledge. There may be unexpected qualitative shifts in how children approach a given task, which result in age-related, but non-linear, patterns of development. If this is the case, attempting to identify and classify patterns of responses on the reading analogy task is particularly important as this may identify that there are alternative pathways to children's reading development other than those suggested in the existing literature (see Ehri, 1998; Goswami, 1993; Goswami & Bryant, 1990). Cluster analytic techniques are used because these have the potential to identify different patterns of responses, or subgroups of children, according to the efficiency they demonstrate in using both orthographic and phonological relations in their early reading.

This study also explored the internal reliability of the real word and non-word versions of the Reading Analogy Task in an attempt to identify which version of the task will provide a more accurate assessment of analogical reasoning skill in beginning reading. Addressing the reliability of the clue-word task is important as the accuracy and reliability of such tasks as a measure of analogical skills in early reading has been recently called into question (Brown & Deavers, 1999; Savage & Stuart, 1998, 2001; Savage, 1997). For example, in line with the phonological priming explanation, there are concerns over the extent to which beginning readers are relying solely on the pronunciation of the clue word, rather than its orthographic features, as a basis for reading the unfamiliar words (see Bowey *et al.*, 1998). In this study, further consideration is given to the two possible strategies that children can use during Reading Analogy Tasks (i.e. visual orthographic analogy strategy or a phonological rhyming strategy) to address the phonological priming explanation further.

Study 1 specifically addressed concerns over the reliability of the Reading Analogy Task. In a recent study, Wood (2002) claims that the potential difficulties associated with the effects of high word frequency may have serious implications for the type of conclusions the research can draw from the clue word studies. According to Wood, the scores on the rime-based items may be artificially inflated by the use of high frequency words. The use of high frequency words as test items, coupled with an apparent tendency in children to generate rhyme based guesses, would result in a number of false positives. A resolution to this problem is to include non-word test items rather than real word equivalents. Such a design would restrict the possibility of children guessing the correct answer and provide a more accurate indication of their analogical skills in reading.

The use of unfamiliar words, non-words or pseudowords, presents an ideal way of examining children's orthographic analogy strategy use without the contamination of word frequency effects or previous word exposure (Wood & Farrington-Flint, 2002). Because young children and beginning readers have had no previous contact with reading unfamiliar words, assessing children's performance using non-word stimuli may provide a more stringent assessment of their ability to recognise orthographic analogies during reading. Nevertheless, with a few exceptions (Brown & Deavers, 1999; Coltheart & Leahy, 1992; Farrington-Flint *et al.*, 2004; Goswami, 1990a; Wood & Farrington-Flint, 2002) non-word test items have not been employed in measures of analogical transfer in early reading. Therefore, it is still a possibility that the orthographic rime analogy effect found in previous investigations could be explained, in part, by the effects associated with word frequency (see Wood, 2002; Wood & Farrington-Flint, 2002). However, whilst the inclusion of non-word test items may prove beneficial in controlling for the effects associated with word frequency in reading, there is currently no information about the reliability of the real word task versus the non-word equivalents. The present study was designed to investigate whether the non-word version of the task provides a

more reliable measure for assessing analogical reasoning in early reading than an equivalent task using real word stimuli.

This research was designed to address three specific hypotheses. First, on the basis of previous research (e.g. Goswami, 1986, 1988, 1990a, 1990b, 1993; Wood, 1999, 2000, 2002), it was expected that children would perform better on the orthographic analogy condition than the equivalent phonological condition or unrelated control condition. It was predicted that this effect would be apparent irrespective of whether real word or non-word items were included. Second, it was expected that individual differences in children's use of orthographic and phonological relations to make analogies would emerge. Third, it was expected that children's early single word reading and receptive vocabulary scores would explain their patterns of analogy in beginning reading.

5.1. Method

5.1.1. Participants

Fifty-five children (34 boys, 21 girls) participated in the study. These children were selected from two schools in Nottinghamshire towards the beginning of the academic year. All children were following the UK National Literacy Strategy, which involves a structured approach in which children are taught a variety of strategies to encourage them to make attempts at decoding unknown words using a phonics approach to reading (e.g., rhyme and phoneme-awareness training) and the use of contextual cues. The mean chronological age of the children was 5 years 11 months ($SD = 5$ months). The mean score for the group on the British Ability Scales II single word reading sub-test was 90.71 ($SD = 7.42$), which equates to an approximate reading age of below 6 years. The mean score of the group on the British Picture Vocabulary Scales II was also within normal limits (101.42, $SD = 10.81$). Children were randomly selected to participate in either the

real word or non-word version of the Reading Analogy Task. Details of participant's allocation to these tasks are summarised in Table 5.1. There was no significant difference between the two groups according to their age, single word reading ability or receptive vocabulary ($p > .05$). All children spoke English as their first language. Parents gave written informed consent to their child's participation.

Table 5. 1

Means (and Standard Deviations) for Age, Vocabulary and Single Word Reading According to Type of Reading Analogy Task

	Total sample	Real word task	Non-word task
Standardised measures ^a	(<i>n</i> = 55)	(<i>n</i> = 28)	(<i>n</i> = 27)
Age (in months)	69.40 (4.58)	70.61 (5.12)	68.15 (3.61)
Single word reading	90.71 (7.42)	89.79 (6.20)	91.67 (8.52)
Receptive vocabulary	101.42 (10.81)	102.89 (10.30)	99.89 (11.30)

^a Standardised scores (Mean = 100, *SD* = 15)

5.1.2. Initial Pre-Test and Screening

All children in reception and year-one classes ($n = 104$) were initially screened to assess their suitability for participation in the study. The children's reading ability was assessed using the British Ability Scales II single word reading test sub-test to establish whether they could demonstrate some emergent reading ability (i.e. whether they were able to read at least one word on the standardised reading test). Children who demonstrated some emergent reading ability were then assessed on their ability to read the words that featured as items in the Reading Analogy Task. Only children who were unable to read any of the test items were recruited to the study ($n = 55$). This procedure ensured that, regardless of the condition they were allocated to later, all children began the study with a limited competence in reading and the pre-test score for all the children taking part in the study was zero (Wood, 1999, 2000, 2002).

5.1.3. Materials

5.1.3.1. Reading Ability

The single word reading sub-test was taken from the British Ability Scales II and included to provide an early baseline measure of children's single word reading ability (Elliot, Smith, & McUlloch, 1996). The words become progressively more difficult and children are required to answer eight or more words correctly out of a set of ten to continue. The child's raw reading score is then converted to a standardised score for the purpose of analysis.

5.1.3.2. Receptive Vocabulary

The British Picture Vocabulary Scales II is similar in design to the Peabody Picture Vocabulary Scales and is a measure of receptive vocabulary (Dunn, Dunn,

Whetton, & Burley, 1997). This requires children to identify pictures that correspond to words spoken by the experimenter. The words become progressively more difficult and children are required to continue until they can only correctly identify four out of a set of twelve items. The child's raw score is then converted to a standardised score prior to analysis.

5.1.3.3. The Reading Analogy Task

The Reading Analogy Task is a revised version of the traditional clue word task developed by Goswami (e.g. Goswami, 1986, 1988, 1990a, 1990b, 1993) which examines children's ability to read new words by reference to the pronunciation of similarly spelled words. Two versions of the Reading Analogy Task were devised comprising of either real word or non-word test items. Children were shown a clue word, which was printed on a single card and told that this clue word might assist them in reading other words. The original clue word remained in view, which enabled the child to refer back to the spelling pattern of that word. Each target word was then placed below the clue word individually and children were asked if they could read it out loud. Only the clue word and its associated target word were presented at any one time. The pack of cards was shuffled before each assessment and no practice, training or explanation was given to any child during the assessment period. The conditions were devised in a way that allowed the exploration of the possibility that children might respond to the phonology of the clue word alone rather than attend to the words' orthographic similarity. This was achieved by including word items that were phonologically similar but orthographically dissimilar to the clue words (Bowey *et al.*, 1998; Goswami, 1990a; Nation *et al.*, 2001; Roberts & McDougall, 2003). If children were found to be performing better on the orthographic analogy words than the equivalent phonological primes, this would support the suggestion that children are sensitive to the orthographic similarity rather than focussing solely on

the pronunciation of the word. On the other hand, if there was no difference between children's performance in the two conditions then phonological priming cannot be ruled out (see Goswami, 1999a).

Two separate tasks were devised to examine children's analogical performance on real word and non-word test items. The same procedure was used in both the real word and the non-word versions of the Reading Analogy Task. To exclude the possibility of obtaining intra-list priming effects and to avoid repetition of vowel sounds, the items for both the real word and non-word versions of the task were each subdivided into two separate lists (see Wood & Farrington-Flint, 2002). These were administered to the children on two separate days and the order of presentation was counterbalanced. (Pilot testing indicated that presenting children with both versions of the task increased the possibility of fatigue and recognising common rhyming patterns between clue words and test words which would often lead to guesses. Therefore, children were presented with either the real word or non-word version of the task only). Each version of the Reading Analogy Task comprised twenty-one clue words and each clue had three target words associated with it corresponding to one the following: (see Appendix A and B for items).

i The orthographic rime analogy. These words shared a common phonological rime and orthographic rime unit with the clue word (e.g., 'bait' - 'wait').

ii The phonological rhyme analogy. These words shared a common phonological rime with the clue word, but share a different orthographic pattern (e.g., 'bait' - 'gate').

iii The unrelated controls. These words shared no common phonological or orthographic overlap with the clue word so the use of analogy would lead to an incorrect response (e.g., 'bait' - 'food').

5.1.4. General Procedure

All testing was carried out in two experimental sessions. As noted previously, children were presented with either the real word version or the non-word version of the task. Following the BAS II single word reading sub-test and BPVS II receptive vocabulary test, children completed List A of the Reading Analogy Task in the first 30 minute session. Children completed List B of the Reading Analogy Task in the second 20 minute session.

5.2. Results

The results are presented in three parts. In the first part, the nature of children's performance on the orthographic and phonological conditions is examined. Analyses for the accuracy of children's responses on the Reading Analogy Task are presented to establish whether children's performance is more successful in the condition that presented orthographic rime analogies than in the corresponding phonological condition. In the second part, cluster analysis is used to attempt to identify meaningful patterns of analogy skills in using orthographic and phonological relations in reading. In the third part, the extent to which children's reading proficiency and vocabulary attainment can predict these patterns of analogy skills is explored using discriminant function analysis.

5.2.1. Analogies in Reading

The goal of first set of analyses was to examine the salience of orthographic analogies in children's reading by examining their performance on the real word and non-word versions of the Reading Analogy Task. In particular, the research aimed to explore the possibility that the children were more accurate in making analogies based on orthographic relations than based solely on phonological relations. If children perform better in the orthographic analogy condition than in the phonological analogy

condition, then this suggests that children are using the visual similarities between the clue word and target word to solve the second word by analogy rather than relying solely on a phonological priming approach.

The means and standard deviations for the frequency of correct responses on the real word and non-word versions of the clue word task are summarised in Table 5.2. Data were analysed using a 2 x 3 (word type: real word, non-word x condition: orthographic rime analogy, phonological rhyme analogy and unrelated controls) analysis of variance, with repeated measures on the last factor. The number of words read correctly by each child was the dependent variable. There was a main effect for condition, $F(2,106) = 202.98, p < 0.001, \eta^2 = .793$, not only across participants, but also across items, $F(2, 80) = 400.29, p < .001, \eta^2 = .91$. Planned comparisons revealed that performance was significantly higher for reading orthographic rime words than the phonological rhyme words, by-subjects, $t(54) = 6.76, p < 0.01$; by-items, $t(41) = 3.89, p < 0.01$, and the unrelated controls, by-subjects, $t(54) = 16.67, p < .00$; by-items, $t(41) = 28.37, p < .001$, suggesting that children were more successful in making analogies on the basis of shared orthographic spelling-sound patterns than relying solely on the shared pronunciation of the word. The children also gave significantly more correct responses for the phonological rhyme words than the unrelated controls, by-subjects, $t(54) = 12.74, p < .001$; by-items, $t(41) = 21.49, p < .001$.

There was no significant main effect for word type, by-subjects, $F(1, 53) = 0.65, p = 0.43, \eta^2 = .01$, and no significant interaction between condition and word type, $F(2,106) = 1.17, p = 0.30, \eta^2 = .02$.

Internal reliability coefficients were calculated for each of the different conditions in the real word and non-word versions of the Reading Analogy Tasks. Internal reliability for each of these tasks was at an acceptable level. The internal reliability of the *orthographic rime analogy* real word items was .85, whereas it was .92 for

the non-word version of this condition. The internal reliability of the *phonological rhyme analogy* real word items was .89, whereas for the non-word version of this condition it was .91. Both the real word and non-word tasks were found to have high internal reliability overall.

Looking at averaged scores across conditions suggests that children are relying on an orthographic rather than purely phonological strategy to read the related words, which replicates previous findings (Goswami, 1986, 1988, 1990a, 1990b, 1993; Goswami & Mead, 1992; Muter *et al.*, 1994; Roberts & McDougall, 2003; Walton, 1995; Wood, 1999, 2000, 2002; Wood & Farrington-Flint, 2002).

Table 5. 2

Means (Standard Deviations) and Cronbach's Alpha Reliability Scores for Children's Accuracy in the Different Conditions for the Real Word and Non-Word Tasks

Conditions ^a	Real word task		Non-word task	
	Mean	α	Mean	α
Orthographic rime analogy	14.25 (4.74)	0.85	13.52 (6.32)	0.92
Phonological rhyme analogy	12.71 (5.66)	0.89	10.81 (6.22)	0.91
Unrelated controls	1.32 (1.85)	0.67	1.44 (1.34)	0.29

^a Maximum score in each condition was 21.

5.2.2. Patterns of Analogy in Beginning Reading

The previous analyses, which used the traditional method to analyse group-level performance, suggests that beginning readers are genuinely using orthographic analogies in early reading and that this effect cannot simply be explained by phonological priming. In the previous literature, this finding is taken as offering strong support that children are using a genuine orthographic analogy strategy in early reading (Goswami, 1988, 1990a, 1993). However, as noted in Chapter 2, a more detailed analytic approach will allow an exploration of possible conceptual underpinnings of analogy for different groups of children. The next stage of analysis was, therefore, to see whether meaningful patterns of the use of orthographic and phonological relationships could be identified for different groups of children using cluster analytic techniques.

Patterns of analogy based on children's accuracy scores on the different conditions included in the Reading Analogy Task were examined using cluster analysis. (Because there was no main effect for task by-subjects in the analysis of variance, the accuracy scores from the real word and non-word tasks are collapsed and combined into one cluster analysis). Cluster analysis was used because it is considered a useful way of identifying characteristic patterns among different children and can often provide a detailed picture of children's competencies across tasks (Siegler, 1996). To identify distinct patterns of analogy skills, Ward's clustering algorithm was applied to the total number of words read correctly in the three task conditions (orthographic analogy, phonological analogy and unrelated controls). A four-cluster solution was selected, which accounted for 91% of the total variance in reading scores. Separate analyses on each variable entered into the cluster analysis indicated that there were significant differences on all three measures across the four clusters, $p < .01$. (Descriptive labels are provided for ease of interpretation). These results are presented in Table 5.3.

Children in the *high reasoning group* ($n = 26$) were very accurate in reading words in the orthographic analogy and phonological analogy conditions. The finding that children showed similar levels of accuracy across both the orthographic and phonological conditions suggests that they may have been applying a blanket rhyming strategy to read analogy words, rather than using connections between shared spelling patterns and shared sound. Children in the *intermediate reasoning group* ($n = 12$) showed a similar pattern of results to the *high reasoning group* although they were less accurate in reading words in the orthographic condition and phonological condition than children in the preceding cluster. Children in the *orthographic reasoning group* ($n = 13$) were more accurate in reading words in the orthographic condition compared to the words in the phonological condition. This was the only group who were significantly better at reading words in the orthographic analogy condition than the phonological prime condition ($p < .01$). Such a finding suggests that this group of children may be making analogies by noticing similarities in the orthographic overlap between words rather than simply applying a blanket rhyming strategy to all the words. Finally, children in the *low reasoning group* ($n = 4$) were the least accurate group and were only able to read a few words in the orthographic and phonological conditions accurately. Given the low levels of accuracy, it is likely that these children often used inaccurate strategies such as guessing the correct answer.

Table 5.3

Means (and Standard Deviations) of Children's Accuracy Scores on the Reading Analogy Task as a Function of Cluster

	Analogy cluster			
	High reasoning	Intermediate reasoning	Orthographic reasoning	Low reasoning
Orthographic relations	18.88 (1.56)	12.67 (1.67)	8.23 (1.64)	3.50 (1.96)
Phonological relations	16.85 (1.97)	11.83 (2.17)	4.77 (1.83)	1.50 (0.58)
Unrelated controls	1.19 (1.30)	2.17 (2.33)	1.38 (1.39)	0.25 (0.50)
<i>n</i>	26	12	13	4

5.2.3. Explaining Patterns of Analogy in Reading

The cluster analytic technique has shown that there is variation in the extent to which beginning readers use orthographic and phonological relations to solve analogical problems in reading. The goal of the third set of analyses was to explore profiles of orthographic and phonological reasoning further by examining the contribution of age; vocabulary and single word reading using direct discriminant function analysis (see Table 5.4). Because of the small sample of children in the *low reasoning group* ($n = 4$), it was necessary to select the three-cluster solution grouping in the discriminant function analysis to prevent reduced power (Tabachnick & Fidell, 2001). This resulted in three distinct groups described as *high reasoning*, *intermediate reasoning* and *orthographic reasoning*.

The discriminant function analysis examined the extent to which children's pre-existing reading knowledge (single word reading and receptive vocabulary) as well as their age could explain patterns of orthographic and phonological relations in reading. Predictors were BAS II single word reading scores, BPVS II vocabulary scores and chronological age. Groups were *high*, *intermediate* and *orthographic reasoning* groups. A total of 51 cases were analysed and the results are summarised in Table 5.4. Univariate analysis of variance revealed that each group differed significantly on single word reading, $F(2, 52) = 7.10, p < .01$, but there were no differences between the groups for either vocabulary, $F(2, 52) = 2.09, p < .01$, or age, $F(2, 52) = 0.33, p < .01$.

Two discriminant functions were calculated with a combined, $\chi^2(6) = 15.92, p < .05$. However, after removal of the first discriminant function, $\chi^2(2) = 0.57, p > .05$, this relationship was no longer reliable. The first discriminant function accounted for 96% of the overall between group variability and maximally separates the *high reasoning* group from the two remaining clusters (the *intermediate* and *orthographic reasoning* groups). As expected, the loading matrix of correlations for predictors suggests that

the best predictor for distinguishing between the *high reasoning* group from the remaining two groups (first function) was only single word reading ($r = .87$) (see Table 5.4). Overall, the discriminant function providing a good fit to the data by successfully predicting 52.7 % of cases. Accurate predictions were made for 57.7 % of scores in the *high reasoning* group, 33.3 % of scores in the *intermediate reasoning* group and finally 58.8% of scores in the *orthographic reasoning* group.

Table 5.4

Means (and Standard Deviations) for Age and Pre-Existing Domain Knowledge as a Function of Reading Cluster

Standardised measures ^a	Analogy cluster		
	High reasoning	Intermediate reasoning	Orthographic reasoning
Age (in months)	69.88 (4.56)	69.33 (5.53)	68.71 (4.03)
Single word reading	93.58 (8.32)	90.50 (5.49)	86.47 (4.95)
Receptive vocabulary	103.23 (10.54)	103.67 (10.13)	97.06 (10.98)
<i>n</i>	26	12	17

^a Standardised scores (Mean = 100, SD = 15)

5.3. Discussion

The purpose of Study 1 was to examine the usefulness of exploring individual differences in children's use of orthographic and phonological relations in early reading. The three hypotheses were supported. First, as expected, the findings demonstrate that young children do have an analogy mechanism available to them in the early stages of learning to read. Specifically, consistent with previous investigations (Goswami, 1986, 1988, 1990a, 1990b, 1993; Goswami & Mead, 1992; Muter *et al.*, 1994; Roberts & McDougall, 2003; Walton, 1995; Wood, 1999, 2000; 2002; Wood & Farrington-Flint, 2002), children were, on average, more accurate in reading words in the orthographic conditions than the phonological primes or unrelated control conditions. This effect was apparent for children's performance on both the real word and non-word types of Reading Analogy Task. Second, as hypothesised, when performance was analysed separately according to each individual's scores, distinct patterns of children's analogy skills were identified. Third, as expected, single word reading helped explain whether children were successfully using orthographic or phonological-based reasoning strategies on the analogy task, however, receptive vocabulary and age offered very little contribution to these patterns of analogy.

A goal of Study 1 was to examine differences in children's performance on the real word and non-word versions of the Reading Analogy Tasks, with a particular interest in exploring whether analogy performance on the revised non-word version of the task would provide a more reliable account of children's analogical performance during reading (Wood, 2002; Wood & Farrington-Flint, 2002). The results showed that the non-word task was a more reliable measure of children's orthographic analogy use when compared to the real word version of the task, and the scores were marginally, although not significantly, lower on the non-word version than for the real word

version. From a methodological perspective, the present findings offer further support to Goswami's original empirical findings because there was so little difference between performances on the two versions of the task. However, in terms of using the clue word task in the current research, it seems that there is a case for suggesting that the use of non-word version of the Reading Analogy Task is a more reliable and conservative measure given the higher internal reliability scores. The inclusion of non-word test items also removes the word frequency effect found in previous studies (see Wood, 2002). This provided good justification for including a non-word version of the Reading Analogy Task in the present research program (Studies 2 and 4).

Using traditional analytic methods of comparing group averages across different conditions, the results showed that overall children were more accurate in reading words in the orthographic analogy condition than the phonological prime or unrelated control conditions. This suggests that young children are sensitive to the varying levels of orthographic and phonological overlap between clue and test words, and are able to use relational similarity based on orthographic features of the two words to reason that the words share the same pronunciation. Although, some degree of phonological priming did occur, this was not sufficient enough to provide an explanation for analogical transfer in beginning reading (Goswami, 1990a). In fact, there was little evidence of equivalent levels of transfer on the different analogy items, which, according to Goswami's criterion confirms that children were not concentrating solely on the pronunciation of the clue word (see Bowey *et al.*, 1998; Nation *et al.*, 2001; Roberts & McDougall, 2003; Savage & Stuart, 1998, 2001 for discussion). Therefore, although there was evidence of some phonological priming effects in children's reading, this was not strong enough to solely explain children's orthographic analogy performance. Rather, it appears that children are making connections between shared spelling patterns and shared sounds in beginning reading (Goswami, 1993; 1999a).

More importantly, the study revealed important individual differences in children's use of orthographic and phonological relations in reading. These profiles suggest that children fall into four distinct groups according to the frequency with which they used orthographic and phonological-type relations across the different trials. Only one group, the *orthographic reasoning* group, were more accurate on the orthographic analogy words than the pure phonological words, suggesting that these children focussed more on the shared orthographic overlap between words and were therefore making genuine rime analogies. Another group, the *high reasoning* group, were highly accurate in reading words in both the orthographic analogy and phonological prime conditions suggesting that they were using a rhyme based phonological approach, rather than an orthographic approach. A further group, the *intermediate reasoning* group, showed a similar pattern of results with similar levels of word reading in both the orthographic analogy and phonological analogy conditions but these were less accurate than the *high reasoning* group. The least sophisticated group, the *low reasoning* group, were particularly poor in reading words in the orthographic and phonological conditions which suggests that these children may have been using more inaccurate or illegitimate strategies than other children and these often led to incorrect answers.

These profiles show how focussing solely on average differences among the sample may overlook important differences within the sample. For example, according to the results from the analysis of variance, it can be claimed that children are making explicit connections between shared spelling patterns and shared sounds and this cannot be explained in terms of a phonological priming effect (see also Goswami, 1990a, 1993). However, when individual differences in children's analogy performance are examined specifically using cluster analysis, a different picture emerges. The findings revealed that one large subgroup of children (*orthographic reasoning* group) could be unambiguously considered to be using more orthographic relationships rather than

phonological relationships to read the target words. This is the only group that appear to have focussed more on the orthographic rime unit between words and are therefore the only group that are making a genuine orthographic rime analogy, rather than using a phonological rhyme. The remaining number of children, who fall into the *high*, *intermediate* and *low reasoning* groups, displayed almost similar levels of accuracy in using orthographic and phonological relations to read target words. It is likely that children in these three groups were focussing on the pronunciation of the words rather than on the orthography and that they focussed more on generating rhyme sounds and making a rhyme analogy than on the visual orthographic rime unit that would lead them to generate a rime analogy. The findings demonstrate the benefits of examining children's reasoning skills using cluster analytic techniques to supplement traditional techniques that simply compare averaged scores across children of the same age. Moreover, examining individual differences in children's ability to generate different types of analogy may provide the basis for a more detailed characterisation of reading development by identifying different pathways to reading success.

These findings are particularly important because they present a theoretical framework that can be examined in more detail in Study 2. As identified in the cluster analysis, there are four children, who fall into the *low reasoning* group, that use no discernable strategy and perform very poorly indeed. There are then twenty-six children, who fall into the *high reasoning* group, who do well on both the orthographic and phonological conditions suggesting that they are using two well-practised strategies in reading. There are a further twelve children, who fall into the *intermediate reasoning* group, who show similar levels of reading in both the orthographic and phonological conditions but are performing less accurately than those children in the *high reasoning* group. This suggests that these twelve children are using both strategies but are less secure with using these to aid their reading. Finally, there are a further

thirteen children in the *orthographic reasoning* group who read twice as many words in the orthographic conditions than the phonological condition but who are less accurate overall than children in the *high* or *intermediate* groups. This suggests that these thirteen children are using one strategy but they are not very secure with exploiting this during reading. However, in order to strengthen these interpretations, the findings need to be replicated in Study 2.

It could also be argued that the current findings help to illustrate how the current debate surrounding orthographic analogies versus phonological priming is misplaced. These seemingly discrepant results can be integrated into one explanation if we explore individual differences in children's performance more closely. Examining distinct patterns in children's use of orthographic and phonological relations in reading raises the possibility that analogies based on phonological similarity alone are an important pathway to reading that is independent to the use of orthographic analogies. If this hypothesis is correct, then there is reason to suggest that aspects of both Goswami's and Bowey et al's arguments are correct and valid: children are using a varying combination of orthographic relations and phonological relations as a route to developing appropriate reading skills (see also Nation *et al.*, 2001). Therefore exploring individual differences in children's analogy performance helps to build a more detailed picture of children's early reading development and allows further exploration of the appropriate skills and strategies that underlie such performance.

Despite providing a useful characterisation of individual differences in early reading, there are nonetheless, three limitations with the present study. First, children's performance was assessed using analogies based on rime-level correspondences and not onset and vowel type analogies (e.g., *bean* - *beak*). This is important in order to help clarify debates regarding the potential importance of rhyme versus beginning analogies to beginning reading (Bowey *et al.*, 1998; Goswami, 1993; Savage & Stuart,

1998, 2001). Second, individual difference patterns were based on children's accuracy scores alone and not solution times. It is likely that including measures of speed, in addition to accuracy, will provide more information about profiles of analogy. Third, despite identifying distinct profiles of reasoning skills, there were no standardised measures of phonological knowledge within the study. A useful extension of this study is to consider the contribution that phonological knowledge (rhyme and phoneme awareness) can make to these patterns of reading analogy. These limitations are addressed in Study 2.

In summary, exploring patterns of analogical reasoning skills in early reading provides a more detailed picture of the types of strategies children use to solve analogical problems in beginning reading and alerts us about the dangers of averaging data across individual children. The findings support the claim that children in early reading have the propensity to use both genuine orthographic rimes based strategies and rhyme based phonological strategies to solve analogical problems within reading and this depends, in part, on children's reading proficiency. Accordingly, a more detailed investigation of the possible alternative routes to reading are addressed in Study 2, by examining whether children's pre-existing reading knowledge, phonological knowledge and their traditional analogical reasoning skills can explain these patterns of analogy in early reading.

CHAPTER SIX

STUDY 2: EXPLAINING PATTERNS OF ANALOGY IN BEGINNING READING

6. Introduction

The purpose of Study 2 was to provide a more detailed examination of the kinds of orthographic and phonological analogies that children use in learning to read. This study was designed to extend the findings of Study 1, which indicated that examining characteristic patterns in children's use of orthographic and phonological relations in word reading sheds new light on the different ways in which children approach the task of making analogies in reading. Study 2 also examined whether children's early pre-existing domain knowledge, phonological skills and other traditional forms of analogical reasoning could explain these patterns of analogy.

Study 2 was designed to extend the findings of Study 1 in three main ways. First, similar to Study 1, patterns of children's performance in using orthographic and phonological relations in beginning reading was explored. Unlike Study 1, however, measures of both accuracy and speed were used as indices of analogical performance in reading across a range of different analogy conditions. Second, systematic comparison between patterns of analogy use and children's phonological knowledge were conducted to test whether individual differences in reading analogy are related to individual differences in phonological awareness and early reading proficiency. Third, the relationship between children's use of analogies in reading and their performance on more traditional forms of analogical reasoning tasks were examined.

The findings from Study 1 illustrated the potential benefits of looking for characteristic patterns in children's use of analogies in beginning reading, although, as

already noted, patterns of analogical reasoning were based solely on accuracy scores across the orthographic and phonological analogy conditions. To provide a more detailed characterisation of individual differences in children's early reasoning skills, measures of both accuracy and speed were taken in Study 2. Indices of speed are particularly useful in the study of children's reading because although children's accuracy levels are often quite high, it is possible that there may be substantial variation in their solution times. Including measures of speed, as well as accuracy, was therefore expected to provide a more detailed characterisation of the possible variation in children's reasoning skills. The analysis in Study 1 also compared children's analogical performance on orthographic and phonological rime words, without any consideration of how they might perform when presented with other analogy types. This is important as analogies need not always involve shared spelling correspondence with rimes; instead children may also be able to make analogies based on other phonological units, such as onsets or individual phonemes (see Goswami, 1993). Therefore, the number of analogy conditions in Study 2 was increased allowing the assessment of the children's ability to make analogies based on shared spelling sequences that correspond with onset and part of the rime (e.g., bean - beak) and shared spelling sequences that correspond with rimes (e.g., bean - mean) for both orthographic pairs and phonological equivalent.

As argued in Chapter 2, although there is evidence that the use of analogy in the context of reading is constrained by children's domain knowledge, the ways in which pre-existing domain knowledge can explain individual differences in reading skills is unknown. The aim of Study 2 was to identify whether children's developing phonological awareness can explain individual differences in analogy use within reading. In keeping with claims that domain relevant knowledge underpins the successful use of analogical-based reading strategies (see Goswami & Bryant, 1990), different types of phonological awareness, corresponding to large phonological units, such as onset and rime

(Goswami, 1990b, 1993; Goswami & Mead, 1992) and also to smaller phonological units such as individual phonemes (Ehri & Robbins, 1992; Roberts & McDougall, 2003; Walton, 1995, 2000; Wood, 2002; Wood & Terrell, 1998) were examined to see whether these can provide a concurrent prediction of analogical reasoning ability in the context of reading. While previous research has argued that analogical reasoning in the context of reading is, in part, constrained by children's knowledge of phonological structures within the reading domain, the extent to which children's emerging phonological knowledge can predict individual differences in analogical reasoning skill awaits empirical support. In Study 2, the research examined whether measures of early rhyme awareness and phoneme awareness could explain individual differences in children's analogising. It was expected that patterns of individual differences would emerge and these would vary according to children's phonological knowledge (Goswami, 1993).

As well as considering children's emerging phonological awareness, Study 2 was also designed to examine whether there is a relationship between traditional analogical reasoning skills (based on visual, causal and thematic relations), and patterns of individual differences in children's use of analogy during reading. As already noted in Chapter 1, comparing patterns of analogy use in reading against traditional analogical reasoning tasks will help to establish whether the ability to use analogy in reading is a domain-specific skill or alternatively whether it is a sub-component of a more traditional analogical reasoning ability. There is very little research that explores the relationship between analogical reasoning in reading and more traditional forms of analogical reasoning skills. Relatively little is known whether forms of analogical reasoning skills, such as the ability to recognise visual similarity or common themes, contribute to children's analogical success on the clue word task (see Wood, 1999). Therefore, the extent to which other traditional reasoning skills, such as the ability to reason about

causal, thematic and visual relations contribute to children's ability to use analogies in early reading requires investigation.

The research was designed to address four specific hypotheses. First, on the basis of the findings from Study 1, it was predicted that children would perform better on the orthographic analogy conditions than the phonological equivalent or unrelated control conditions. Second, it was hypothesised that different profiles of reasoning ability would emerge that reflect individual differences in children's analogical performance on the Reading Analogy Task. Third, on the basis of previous experiments (Goswami, 1990a, 1990b, 1993; Goswami & Mead, 1992; Muter *et al.*, 1994; Roberts & McDougall, 2003; Walton, 1995; Wood, 1999, 2000, 2002; Wood & Terrell, 1998), it was expected that children's phonological knowledge would account for, at least in part, patterns of analogical reasoning in reading. Fourth, it was expected that traditional forms of analogical reasoning skill would offer some concurrent prediction of children's analogical reasoning ability on the Reading Analogy Task. In particular, it was anticipated that performance on the causal, thematic and visual proportions tasks would be able to discriminate between different profiles of reading analogy (see Wood, 1999).

6.1. Method

6.1.1. Participants

Fifty-one children (25 boys, 26 girls) participated in the study. The children's ages ranged from 5 years 1 month to 6 years 4 months (Mean = 5 years 6 months, $SD = 4$ months). The children were selected from two schools in Nottinghamshire and were tested towards the beginning of the academic year. As before, all children were following the UK National Literacy Strategy, which involves a structured approach in which children are taught a variety of strategies to encourage them to make attempts at decoding

unknown words using a phonics approach to reading (e.g., rhyme and phoneme-awareness training) and the use of contextual cues. The mean reading ability score of the children on the British Ability Scales II single word reading sub-test was 94.08 ($SD = 7.11$), which equates to an approximate reading age of 5 years 8 months. The mean score of the group on the British Picture Vocabulary Scales II was within normal limits (103.84, $SD = 9.39$). All children spoke English as their first language. Parents gave written informed consent to their child's participation.

6.1.2. Initial Pre-test and Screening

Similar to Study 1, children were in reception and year-one classes ($n = 138$) and were recruited according to their level of reading proficiency. Single word reading ability was assessed using the British Ability Scales II single word reading sub-test in order to establish that children could demonstrate some emergent reading skill. Children were then pre-tested on their ability to read the non-words that would be used in the Reading Analogy task. As before, to be included in the study, children had to demonstrate initial reading ability, reading at least one word from the single-word reading sub-test, but only those who were unable to read any of the non-words that were to be used in the Reading Analogy Task were selected ($n = 51$). This ensured that all children began the study within the same limits of competence in reading and prevented the need to calculate pre- and actual test analogy scores (Wood, 1999, 2000, 2002).

6.1.3. Materials

6.1.3.1. Reading Ability

The single word-reading sub-test was taken from the British Ability Scales II and included in the study to provide an early baseline measure of children's single word reading ability (Elliot *et al.*, 1996). The words become progressively more

difficult and children are required to answer eight or more words correctly out of ten to continue. The child's raw reading score is then converted to a standardised score.

6.1.3.2. Receptive Vocabulary

The British Picture Vocabulary Scales II is a measure of receptive vocabulary, which requires children to identify pictures that correspond to words spoken by the experimenter (Dunn *et al.*, 1997). The words become progressively more difficult and children are required to continue until they can only get four words correct out of a set of twelve items. The raw score was then converted to a standardised score for the purpose of analysis.

6.1.3.3. Backward Digit-Span

The backward digit span taken from the British Ability Scales II and was included to provide a measure of memory span (Elliot *et al.*, 1996). This task consisted of 6 trials, each trial containing 5 items in total. Each trial increased in difficulty. The children were given a sequence of digits and required to repeat that sequence backwards. Digits were presented with at a regular pace with a two second interval between the presentations of each digit. Children were given one practice trial where feedback was provided in order to familiarise them with the task. One point was scored for each sequence of digits repeated correctly.

6.1.3.4. Rhyme Awareness

The Rhyme Awareness Task was included in the study to provide a measure of children's sensitivity to spoken rhyme (Frederickson, Frith, & Reason, 1997). In this task the children heard three words spoken, two of which rhymed. The children were asked to say which two words rhymed. They completed four practice items (during which

feedback is provided) followed by up to 21 test items that increased in difficulty. Each child scored 1 point for each pair of words named correctly out of 21.

6.1.3.5. Phoneme Deletion

The children's understanding of phoneme units was assessed using a phoneme deletion task, as used in Wood (1999, 2000, 2002) which required the child to delete either the initial or final phoneme from a word to create a new word: e.g., "Try to say 'car' without saying the /k/". The task began with three practice items for the initial phoneme deletion sub-scale, followed by the actual test items. Corrective feedback was allowed during the practice items to ensure the child understood the instructions, but no feedback was given during the actual test items. The same sequence is followed for the final deletion sub-scale. There were twelve items in the initial phoneme sub-scale, and twelve items in the final phoneme sub-scale. The children received 1 point for each correct deletion made.

6.1.3.6. Traditional Measures of Analogical Reasoning

A series of traditional analogical reasoning tasks were included in the study to provide a measure of children's general analogical reasoning ability. This comprised of three separate reasoning tasks designed to assess children's ability to complete pictorial A:B::C: analogies based on familiar relations. Each of the three tasks used the same experimental procedure but varied in terms of the types of relations that children were required to use in order to complete the problems successfully (see Appendix G, Figures 1, 2 & 3). Rather than using picture drawings, black and white digital still photographs were included in each task to ensure that each child could correctly identify each picture accordingly and to avoid the possible confound of ambiguity. The trials were presented on a computer laptop, which allowed sensitive measures of accuracy and speed to be

recorded. (The speed and accuracy scores were adjusted to take into account the different number of choices available on each of the three analogical reasoning tasks. These scores were weighted by multiplying the scores obtained (out of 10) by the total number of choices available).

a. The causal reasoning task. The causal reasoning task assessed young children's ability to use knowledge of physical causal relations (such as 'melting' or 'cutting'), as a basis for completing analogies in the form of *bread is to sliced bread as apple is to sliced apple* (Goswami, 1989). This task comprised 10 trials. In each trial, children were presented with a sequence of three pictures (e.g., *bread, sliced bread* and *apple*). Children selected their answer from four alternatives, the correct alternative (e.g., slice of bread) or a wrong object correct physical change (e.g., slice of cake), correct object, wrong physical change (e.g., bruised apple), mere appearance match (e.g., ball). One point was scored for each correct trial.

b. The thematic reasoning task. The thematic reasoning task assessed young children's ability to use their knowledge of thematic relations (such as 'lives in', 'wears') to complete analogies in the form of *gloves are to hands as shoes are to feet* (Goswami & Brown, 1990). This task comprised 10 trials. In each trial, children were presented with a sequence of three pictures (e.g., *gloves, hands, shoes*). Children selected their answer from one of four alternatives, the correct answer (e.g., feet), a strong thematic associate (e.g., socks); a category match (e.g., boots), or a mere appearance match (e.g., shoes). One point was scored for each correct trial.

c. The visual reasoning task. The visual reasoning task assessed young children's ability to complete analogies on the basis of shared visual relations (Wood, 1999). This task comprised 10 trials. In each trial, children were asked to look

closely at the different shapes, compare them and explain how the shaded part had changed. Children were presented with a sequence of three pictures and selected their answer from five alternatives, the correct answer, correct object-wrong transformation, wrong object-correct transformation; a high similarity match to 'B' inverted, or a mere appearance match. One point was scored for each correct trial.

6.1.3.7. The Reading Analogy Task

The Reading Analogy Task is a revised version of the same task used in Study 1 using non-word items. It was included in the study as a method of exploring children's ability to recognise how the spelling-sound pattern of one non-word can be used as a basis for working out the spelling-sound pattern of similarly spelled non-words. A computer version of the task was devised in order to obtain a measure of the accuracy and speed of each individual response. During the task, the clue word appeared in the centre of a 22.5cm screen and the child was told its pronunciation and told that this clue-word might help them to read other nonwords. The experimenter hit a timing key to present a new target word and children were asked if they were able to read this particular target word. The original clue word remained in view, which enabled the child to refer back to the spelling pattern of that particular word. The assessor hit a key when the child stated their answer in order to record solution times. (As before, although a voice activated timing system was the most accurate way to record individual solution times, these scores were unreliable given that children often reasoned aloud).

Similar to Study 1, two sets of matched word lists were devised containing non-word items. However, unlike Study 1, only non-word items were included. The inclusion of non-word items assisted in controlling for high word frequency (Wood & Farrington-Flint, 2002). Moreover, the conditions were devised in a way that allowed us to explore

the possibility that children might respond to the phonology of the clue word rather than the words orthographic similarity (see Appendix C). This was achieved by including items that were phonologically similar but orthographically dissimilar to the clue word items (Nation *et al.*, 2001). However, unlike Study 1, more conditions were included in the present study. The Reading Analogy Task comprised sixteen clue words and each clue had five target non-words associated with it corresponding to the following:

i The orthographic rime analogy. These non-words shared a common phonological rime and orthographic rime unit with the clue word (e.g., ‘kurp’ - ‘nurp’).

ii The phonological rime analogy. These non-words shared a common phonological rime with the clue, but share a different orthographic pattern (e.g., ‘kurp’ - ‘herp’).

iii The orthographic beginning analogy. These non-words shared a common phonological and orthographic beginning as the clue, up to but not including the final phoneme (e.g., ‘kurp’ - ‘kurn’).

iv The phonological beginning analogy. These non-words shared a common phonological beginning up to, but not including, the last phoneme and similarly share a different orthographic pattern to the clue (e.g., ‘kurp’ - ‘kerf’).

v The unrelated controls. These non-words shared no common phonological or orthographic overlap with the clue (e.g., ‘kurp’ - ‘helt’).

6.1.4. General Procedure

Each child was interviewed individually on three separate occasions. In the pre-test session, following the British Ability Scales II single word reading test, the children were asked to read the list of words that were to be used in the Reading Analogy Task. On the basis of being unable to read any of these pre-test words, the children were recruited to

the study. The children then completed the British Picture Vocabulary Scales II, Rhyme Awareness task and Phoneme Deletion task in the first 30-minute session. They completed List A of the Reading Analogy Task and the visual reasoning task in the second 30-minute session. In the third 30-minute session, the causal and thematic analogical reasoning tasks and List B of the Reading Analogy Task was administered. The order of presentation of the tasks was randomised between children.

6.2. Results

The results are presented in four parts. In the first part, the salience of analogy to young beginning readers is explored. The extent to which the children are able to make orthographic analogies compared to their performance on the corresponding phonological items is investigated. In the second part, the research examined whether children's single word reading, phonological knowledge and their traditional analogical reasoning scores could predict their use of orthographic and phonological types of analogy in early reading. In the third part, individual differences in young children's use of orthographic and phonological relations in beginning reading are explored using cluster analysis. In the fourth part, the extent to which single word reading; phonological knowledge and traditional analogical reasoning skills, can explain patterns analogy is examined using discriminant function analysis.

6.2.1. Analogies in Reading

Similar to Study 1, the goal of the first set of analyses was to examine whether orthographic analogy is of salience to young beginning readers and whether this aspect of early reasoning skill can be distinguished from the effects associated with phonological priming. However, unlike Study 1, two separate analyses were conducted to examine the nature of children's responses according to the accuracy and speed across each condition.

Table 6.1 summarises the mean scores and standard deviations for the speed and accuracy of children's performance on each of the analogy items. Cronbach's Alpha internal reliability coefficients for the five conditions are also summarised in Table 6.1. Similar to Study 1, high levels of internal reliability were found with the non-word tests items. The speed and accuracy of children's scores were analysed using one-way analysis of variance. The experimental design consisted of a one within-subject factor design (condition).

In the accuracy analyses, the results showed a main effect for condition, by-subjects: $F(4, 50) = 77.81, p < .001, \eta^2 = .607$; by-items: $F(4, 75) = 59.98, p < .001, \eta^2 = .762$. Planned comparisons revealed by-subjects, that orthographic rime words were read more accurately than the phonological rime words, by-subjects: $t(50) = 3.18, p < .001$, although by-items, this effect was not found to be significant, by-items: $t(30) = 2.01, p = .053$. As expected, children were more proficient in reading orthographic rime words than the orthographic beginning words, by-subjects: $t(50) = 4.08, p < .001$; by-items: $t(30) = 3.74, p < .001$. Children were also more proficient in reading the orthographic beginning words than reading the phonological equivalents, by-subjects: $t(50) = 5.17, p < .001$; by-items: $t(30) = 3.01, p < .01$.

To explore whether different patterns of analogical performance emerge on the basis of children's individual solution times, a second analysis of variance was conducted. (Analyses only included individual solution times of less than 60 seconds and excluded incorrect responses). The solution time analyses showed a main effect for condition by-subjects, $F(4, 50) = 2.65, p < .01, \eta^2 = .050$, although not by items, $F(4, 75) = 2.00, p > .05, \eta^2 = .010$. Planned comparisons revealed that by-subjects children were no quicker in reading words sharing orthographic and phonological rimes than those with purely phonological rhymes, $t(50) = .03, p > .05$, and no quicker in reading the orthographic and phonological beginning words than those words with purely phonological

beginnings, $t(50) = .37, p > .05$. However, the children did respond more quickly when reading the orthographic rime words in comparison to the orthographic beginning words, $t(50) = 2.42, p < .05$.

In order to examine the relations between orthography and phonology further, composite measures of orthographic and phonological reasoning skills were calculated by averaging the z-scores for the relevant measures. Scores for the *orthographic rime* words and *orthographic beginning* words were combined to provide a composite measure of *orthographic analogy* skill. Scores for the *phonological rhyme* words and the *phonological beginning* words were combined to provide a composite measure of *phonological analogy* skill. Cronbach's alpha internal reliability coefficients for the new composite measures were at an acceptable level (composite orthographic analogy, 0.81; composite phonological analogy, 0.86). All analyses were performed using these composite scores.

Table 6. 1

Means (and Standard Deviations) for the Speed and Accuracy of Children's Scores on the Reading Analogy Task and the Traditional Analogical Reasoning Tasks

	Accuracy	Speed ^c	α
The Reading Analogy Task ^a			
Orthographic rime analogy	10.37 (3.28)	5.67 (3.50)	0.71
Phonological rhyme analogy	9.31 (3.67)	5.68 (3.65)	0.77
Orthographic beginning analogy	8.12 (3.81)	7.04 (4.25)	0.79
Phonological beginning analogy	6.04 (3.94)	7.28 (5.78)	0.82
Unrelated controls	2.33 (2.58)	5.43 (5.32)	0.75
Traditional Reasoning Tasks ^b			
Thematic reasoning	5.51 (1.45)	4.82 (1.65)	0.61
Causal reasoning	5.90 (1.53)	4.38 (1.51)	0.52
Visual reasoning	4.10 (1.72)	8.04 (3.14)	0.55

^a Accuracy score out of 16. ^b Accuracy score out of 10.

^c Solution-time in seconds (analyses include individual solution time of less than 60 seconds and includes correct responses only).

6.2.2 Concurrent Prediction of Reading Analogy

The aim of the second set of analyses was to examine possible covariations between children's reading analogy skills, their traditional analogical reasoning skills and their phonological knowledge. In particular, these sets of analyses were concerned with assessing the power of traditional analogical reasoning scores and phonological knowledge as predictors of orthographic and phonological analogy skills in reading.

Before examining concurrent predictors of using orthographic and phonological relations in reading, the raw correlations between single word reading ability, receptive vocabulary, short-term memory, traditional analogical reasoning skill and orthographic and phonological analogies were examined. The correlation matrix, reported in Table 6.2, outlines the relationship between each of the individual variables. As expected, there are strong correlations between single word reading, rhyme awareness and phoneme awareness and each of these measures are strongly related to children's orthographic analogy scores. Also, measures of single word reading and phonological knowledge are all significantly correlated with the composite measure of phonological analogy score, although correlations for short-term memory and receptive vocabulary scores were low and neither of these measures could significantly predict either measure of orthographic or phonological forms of reasoning by analogy. However, there are strong correlations between measures of traditional analogical reasoning skill (causal, thematic and visual reasoning) and children's orthographic and phonological analogy scores, which suggest that aspects of traditional analogical reasoning skills may be strong predictors of analogies in the context of reading. The contribution of phonological factors and traditional analogical reasoning skills were, therefore, examined further using a series of fixed order stepwise regression analyses.

Table 6.2

Correlations between Reading Analogy Skills, Phonological Skills and Traditional Analogical Reasoning Skills

	1	2	3	4	5	6	7	8	9	10
1. Orthographic analogy	-									
2. Phonological analogy	.820**	-								
3. Single word reading	.531**	.501**	-							
4. Vocabulary	.170	.198	.361**	-						
5. Short-term memory	.080	-.062	.232	.273	-					
6. Rhyme awareness	.449**	.465**	.541**	.328*	.122	-				
7. Phoneme awareness	.534**	.583**	.499**	.153	.029	.527**	-			
8. Thematic reasoning	.316*	.261	.056	-.040	.053	.350*	.228	-		
9. Causal reasoning	.227	.331*	.205	.051	-.261	.273	.401*	.041	-	
10. Visual reasoning	.389**	.433**	.016	-.031	-.162	.103	.183	.060	-.042	-

Note. * p < .05 ** p < .001

To assess the power of traditional analogical reasoning ability and early phonological knowledge as predictors of reading analogy, two series of fixed order stepwise regression analyses were carried out with composite orthographic and phonological analogy scores as predictors. The order in which the traditional analogical reasoning tasks were entered into the regression model was varied systematically to examine the extent to which certain forms of analogical reasoning tasks act as unique predictors of reading analogy when the effects of other pre-existing domain knowledge measures had been controlled. (Given the low ratio between cases and independent variables, the regression analyses may have reduced power and results should be interpreted with caution).

In the first analysis, the composite orthographic analogy scores were treated as the dependent variable with age, single word reading, phonological awareness scores and traditional analogical reasoning scores as predictors. Age, was entered at step 1 and single word reading, rhyme awareness and phoneme awareness at steps 2 to 4. The causal, thematic and visual reasoning scores were entered into the regression model in all possible combinations at steps 5 to 7 (Receptive vocabulary and short-term memory scores were not entered into the regression model because they failed to account for any appreciable variance in orthographic and phonological analogy scores in the correlational analysis). The results from this analysis are provided in Table 6.3 and show that age can account for a significant amount of variance when entered into the model at step 1 (14%, $p < .01$). As expected, measures of single word reading (21%, $p < .01$) can account for significant variance in orthographic analogy skills after the contribution of age has been systematically controlled. The only measure of traditional analogical reasoning skill that can explain orthographic analogy is visual reasoning skill (5%, $p < .05$).

In the second series, phonological analogy scores were treated as the dependent variable and phonological knowledge and traditional analogical reasoning scores as predictors. A similar pattern of findings emerged. Age accounted for a

significant amount of variance (21%, $p < .01$), followed by single word reading (21%, $p < .01$). Phoneme awareness was also found to account for an additional 6% of the variance after age and single word reading had been entered into the regression model. The only unique predictor of phonological analogy scores in reading, after all other measures had been taken into account was visual reasoning skills (7%, $p < .01$).

Table 6.3

Fixed Order Regression Analyses with Composite Orthographic and Phonological Analogy Scores as the Dependent Variable and Age, Pre-Existing Domain Knowledge and Traditional Analogical Reasoning Scores as Predictors

Steps 1 to 7	Orthographic analogy			Phonological analogy		
	R ²	R ² Change	F value	R ²	R ² Change	F value
Step 1. Age (months)	.14	.14	8.04**	.21	.21	12.96**
Step 2. Word reading	.37	.23	17.54**	.42	.21	17.63**
Step 3. Rhyme skills	.40	.03	2.17	.45	.03	2.83
Step 4. Phoneme skills	.44	.04	3.17	.51	.06	5.14*
Step 5. Thematic reasoning	.46	.02	1.95	.51	.00	.36
Step 6. Causal reasoning	.46	.00	.06	.52	.00	.20
Step 7. Visual reasoning	.42	.06	5.39*	.59	.07	7.47**

Note. * p < .05 ** p < .001

6.2.3. Patterns of Analogy in Beginning Reading

The goal of this set of analyses was to examine characteristic patterns in children's analogical reasoning skills in early reading. Similar to Study 1, cluster analysis was used to explore whether distinct patterns of individual differences in the speed and accuracy with which young children perform analogies could be identified. Distinct patterns of analogical skills were identified using Wards clustering algorithm. The clustering algorithm was applied to the number of orthographic and phonological analogy words read correctly and the average solution times for each of these conditions (using the composite orthographic and phonological scores). Standardised scores were used in order to take into account different weightings of variables and to ensure an equal contribution from the accuracy and solution time data. The results from the cluster analysis are summarised in Table 6.4. (Analysis of variance revealed that the groups were distinct and they were significantly discriminated by all predictors, significance level set at $p < .05$).

A four-cluster solution, which accounted for 75% of the total variation in children's scores, was selected. Children in the *high reasoning group* ($n = 14$), were adept at recognising both orthographic and phonological analogies, responding efficiently to both types of analogies in the Reading Analogy Task. Equivalent levels of transfer across both conditions suggests that children were using a phonological-based reading strategy to read the non-word items, rather than making connections between shared spelling patterns and shared sound. Children in the *intermediate reasoning group* ($n = 16$), showed a similar pattern of results to the *high reasoning group* although they were less accurate and slower in reading the words in the orthographic analogy condition and phonological condition than children in the preceding cluster. By comparison, children in the *orthographic reasoning group* ($n = 10$), were generally slower in both the orthographic and phonological conditions, but in terms of orthographic accuracy, there was little difference

between the *intermediate reasoning* and *orthographic reasoning* groups. Children in this cluster were less able to read words in the phonological conditions and were slower. This advantage for reading orthographic analogy words provides an indication that the children in this group were reading the related words on the shared orthographic overlap between words (e.g., orthographic based reading strategy) rather than simply applying a phonological-based reading strategy across all conditions (e.g., phonological prime). Children in the *low reasoning group* ($n = 11$), were slower in reading words in all of the conditions than the previous clusters. However, children in this group were more accurate in reading the words in the orthographic condition than the phonological condition. Their low levels of accuracy overall suggest that these children may have been using inappropriate or inaccurate strategies that often led them to the incorrect pronunciations of words.

In support of the findings from Study 1, an analysis of variance revealed that these distinct patterns in reading analogy could not be explained by children's age, $F(3, 47) = 2.10, p > .05$.

Table 6.4

Means (and Standard Deviations) of the Accuracy and Speed of Composite Orthographic and Phonological Accuracy Scores as a Function of Analogy Cluster

	Analogy cluster			
	High reasoning	Intermediate reasoning	Orthographic reasoning	Low reasoning
Accuracy scores ^a				
Orthographic analogy	26.14 (2.21)	17.19 (2.14)	17.50 (4.33)	11.55 (2.51)
Phonological analogy	23.14 (3.3.7)	16.13 (3.86)	11.90 (4.51)	7.45 (2.58)
Solution times ^b				
Orthographic analogy	3.57 (0.55)	4.35 (1.12)	9.75 (2.50)	9.74 (2.47)
Phonological analogy	3.75 (0.64)	4.78 (1.29)	12.20 (3.58)	7.23 (2.72)
<i>n</i>	14	16	10	11

^a Accuracy scores out of 32.

^b Solution-time in seconds (analyses include individual solution time of less than 60 seconds and includes correct responses only).

6.2.4. Analogies in Reading and Traditional Reasoning Skills

The goal of the fourth set of analyses was to examine the relationship between patterns of individual differences in children's reading analogy, their traditional analogical reasoning skills and their phonological knowledge. To establish the extent to which children's knowledge of the reading domain and their traditional analogical reasoning skills can explain patterns of individual differences in children's analogy skills, two direct discriminant function analyses were conducted (see Table 6.5). In each discriminant function, groups consisted of *high reasoning*, *intermediate reasoning*, *orthographic reasoning* and *low reasoning*, as indexed by cluster membership.

The first direct discriminant function analysis examined relations between measures of this analogical component of reading and other forms of traditional analogical reasoning skills. Predictors were frequency of correct responses on the thematic relations, causal relations and visual relations task. A total of 51 cases were analysed. As Table 6.5 shows, univariate analysis of variance revealed that none of the groups differed significantly on each of the three predictors: for thematic relations, $F(3, 47) = 1.38, p > .05$, for causal relations, $F(3, 47) = 1.18, p > .80$, or for visual relations, $F(3, 47) = 1.60, p > .05$. Three discriminant functions were calculated with a combined, $\chi^2(9) = 12.24, p > .05$. After removal of the first function, $\chi^2(4) = .90, p > .05$ and second function, $\chi^2(1) = .27, p > .05$, there was no significant association between groups and predictors, suggesting that individual differences in reading analogy are not explained by children's more traditional analogical reasoning skills.

Although the traditional analogical reasoning skills could not predict performance in each of the four clusters, the next step was to examine whether children's pre-existing domain knowledge could offer any explanation. A second discriminant function analysis examined whether children's knowledge of the reading domain, specifically, word reading and phonological skills, could explain patterns of analogy in reading.

(Short-term memory and vocabulary scores were not included in the discriminant function because of their poor correlation with the outcome measures shown in Table 6.2).

Predictors were children's single word reading, rhyme awareness and phoneme awareness. As before, a total of 51 cases were analysed and the results from the discriminant function are summarised in Table 6.5. A series of univariate analysis of variance revealed that the four groups differed significantly on each of the three predictor variables: single word reading, $F(3, 47) = 8.44, p < .01$, rhyme awareness, $F(3, 47) = 6.22, p < .01$, and finally phoneme awareness, $F(3, 47) = 4.63, p < .01$.

Given these significant differences between groups, three discriminant functions were calculated with a combined, $\chi^2(9) = 26.57, p < .01$. After removal of the first discriminant function, $\chi^2(4) = 1.01, p > .05$, and removal of the second function, $\chi^2(1) = .01, p > .05$, however, this relationship was no longer reliable. The results suggest that the first discriminant function accounted for 64% of the overall between group variability. The first discriminant function maximally separates the *high reasoning* group from the three remaining groups. The loading matrix of correlations for predictors suggests that the best predictors for distinguishing between the *high reasoning* group and the remaining groups (the first function) are single word reading ($r = .86$), rhyme awareness ($r = .74$) and phoneme awareness ($r = .62$). This finding suggests that pre-existing reading skills can best explain the differences between children in the high reasoning group and those children in the remaining groups in terms of their analogical performance in reading. Overall, the direct discriminant function analysis provided a good fit to the data by successfully predicting 54.9 % of cases. Accurate predictions were made for 70% of scores in the *orthographic reasoning*, 64% of scores in the *intermediate reasoning*, 25% of scores in the *high reasoning* and 72% of the *low reasoning* group.

Table 6.5

Means (and Standard Deviations) for Children’s Traditional Analogical Reasoning Skills and their Pre-Existing Domain Knowledge as a Function of Analogy Cluster

	Analogy cluster			
	High reasoning	Intermediate reasoning	Orthographic reasoning	Low reasoning
Traditional reasoning skills				
Thematic reasoning	24.29 (5.31)	21.75 (5.84)	22.00 (5.73)	19.64 (6.05)
Causal reasoning	25.14 (6.16)	23.75 (6.45)	24.40 (4.79)	20.73 (6.41)
Visual reasoning	23.21 (7.99)	21.87 (10.31)	19.00 (8.10)	16.36 (5.95)
Pre-existing domain knowledge				
Single word reading ^a	98.43 (5.69)	96.06 (8.00)	87.91 (3.27)	91.60 (5.06)
Rhyme awareness	12.79 (2.19)	10.50 (4.23)	8.80 (4.32)	6.91 (2.95)
Phoneme awareness	14.64 (2.76)	11.81 (4.45)	10.90 (4.58)	8.27 (5.33)
<i>n</i>	14	16	10	11

^a Standardised scores (mean = 100, *SD* = 15).

6.3. Discussion

The purpose of the study was to explore individual differences in children's use of orthographic and phonological relations in reading more closely and to investigate the extent to which pre-existing domain knowledge and traditional analogical reasoning skills contribute to these patterns of individual differences. Three of the four hypotheses proposed in the study were supported. First, as expected, children did perform better on reading the non-words in the orthographic analogy conditions than those in the phonological equivalents or unrelated control conditions. Second, as hypothesised meaningful profiles of reasoning ability were identified according to the speed and accuracy of children's performance on the Reading Analogy Task. It is noteworthy that the patterns of orthographic and phonological relations in the present study are remarkably similar to those identified in Study 1. Third, children's phonological knowledge could discriminate between these different patterns of analogy (see Goswami, 1990a, 1990b, 1993; Muter, Snowling & Taylor, 1994; Walton, 1995; Wood, 1999, 2000, 2002). Fourth, although traditional analogical reasoning skills (e.g., visual reasoning) concurrently predicted children's use of orthographic and phonological relations as a basis for making analogies in reading, their scores on the causal, thematic and visual proportions tasks were unable to discriminate between the different profiles of reasoning skills.

As with Study 1, the first analysis examined the salience of the orthographic analogy effect in beginning reading. However, in Study 2, indices of solution time as well as accuracy were analysed to provide a more detailed assessment of children's performance. Although there was clear evidence that the children were more successful in reading words in the orthographic analogy condition than the phonological condition between the beginnings of words ($p < .01$), their performance on the rime related items in

the task was less clear. Unlike Study 1, there were increased levels of phonological priming found in the present study. In three of the possible four planned comparisons for rime analogy, (by items/subjects, accuracy/speed), there were no significant differences in performance between orthographically similar word pairs and the phonologically similar word pairs. According to the phonological priming suggestion, the findings here would seem to suggest that the children were concentrating solely on the pronunciation of clue word and were not attending to the orthographic overlap between clue and test words (Bowey *et al.*, 1998; Nation *et al.*, 2001; Roberts & McDougall, 2003; Savage & Stuart, 1998).

However, it is possible that children may be using a combination of orthographic and phonological relations to read target items in the Reading Analogy Task. This is important because it implies that children's use of phonological relations is important in their own right. The findings illustrate the varying degrees to which some children analogue orthographically whilst others use phonological priming. The possible educational implication of this finding is that teaching children to explicitly look for shared conceptual relations between words not only based on orthographic relations but also phonological relations in early reading is a prominent way to develop early reading.

Study 2 also examined concurrent predictors of reading analogy skills in beginning reading. Previous research has shown how aspects of children's rhyme awareness, phoneme awareness and single word reading skill are important predictors of orthographic forms of analogical reasoning in beginning reading (Goswami, 1990b, 1993; Goswami & Mead, 1992; Muter *et al.*, 1994; Roberts & McDougall, 2003; Wood, 1999, 2000, 2002; Wood & Farrington-Flint, 2002). However, there has been less research on predictors of alternative types of analogies, such as phonological analogies in early reading. The results from the regression analyses showed that single word reading was an excellent predictor, accounting for 23% in orthographic analogy scores and

21% in children's phonological analogy scores in beginning reading. Surprisingly, children's phonological knowledge failed to predict reading analogy scores once age and single word reading was controlled. The finding that vocabulary and phonological knowledge fails to predict children's use of orthographic analogies in beginning reading is inconsistent with previous experimental findings (Bowey & Hansen, 1994; Bowey & Underwood, 1996; Goswami, 1990a, 1990b, 1993; Goswami & Mead, 1992; Muter *et al.*, 1994; Roberts & McDougall, 2003; Walton, 1995). The more common finding that orthographic analogy use increases with word reading proficiency and vocabulary skill may be an artefact of calculating improvements from pre-test to actual test scores (see also Wood, 1999, 2000, 2002)

As hypothesised, important individual differences in children's use of orthographic and phonological relations in early reading were identified. The profiles identified were based on the speed and accuracy of children's ability to use orthographic and phonological relations to solve related analogy problems in the Reading Analogy Task. The profiles are particularly important because they separate children into different groups according to the efficiency with which they solved orthographic analogies and responded to the phonological prime items. Similar to the results from Study 1, the current profiles revealed that one group of children in the *high reasoning* group were fast and accurate in reading words in both the orthographic analogy and phonological prime conditions. Another group of children in the *intermediate reasoning* group showed a similar pattern of results with similar levels of reading accuracy in both the orthographic and phonological conditions but these children were slightly less accurate and were slower than children in the previous group. These children who do well on both the orthographic and phonological conditions suggest that they are using two well-practised strategies in reading. A third group of children, the *orthographic reasoning* group, were as accurate in reading the orthographic analogy items as those children in the

intermediate reasoning group, but were less accurate in reading the phonological prime words. A fourth group of children, the *low reasoning* group, showed a slight advantage for reading words in the orthographic condition than words in the phonological condition but their performance was underscored by slow responses. Generally these children were less accurate and slower than that of children in the other clusters. Thus it seems that the third and fourth groups of children identified were the most attentive to the orthographic similarity between the clue words and target words and least susceptible to phonological priming effects. These profiles of analogy provide further support to those identified in Study 1 and illustrate the benefits of identifying individual difference patterns in children's early reading.

As expected, systematic relations between children's analogy profiles and their word reading and early phonological knowledge were identified. Specifically, the scores of children in the four clusters were compared against standardised tests of single word reading, rhyme awareness and phoneme awareness. An interesting pattern of results emerged showing linear trends in domain knowledge across the four groups. As expected, children in the *high* and *intermediate reasoning* group had higher levels of single word reading and early phonological skills, than children in the remaining two groups (*orthographic* and *low reasoning* groups). Therefore, in support of the findings from Study 1, it appears that increases in the accuracy of children's analogical reasoning skills in beginning reading are associated with advances in reading proficiency and phonological knowledge (see Goswami, 1993).

The identification of these different profiles or clusters, however, also has important theoretical implications for evaluating the phonological priming debate (Bowey *et al.*, 1998; Goswami, 1999c; Nation *et al.*, 2001; Roberts & McDougall, 2003; Savage & Stuart, 1998, 2001). It is possible that the current profiles of analogical reasoning skills indicate qualitative changes in beginning reading. It is apparent that children

who fall into the 'higher' analogy groups (*high* and *intermediate reasoning* group) show almost equivalent levels of transfer in reading the orthographic items and phonological primes, which according to Goswami's own strict criterion demonstrates high levels of phonological priming. This indicates that children in these clusters might have been using a phonological approach in their responses to all word pairs, rather than using a more traditional orthographic analogy approach to word reading (see Goswami, 1990). In contrast, children in the 'lowest' groups (the *orthographic* and *low reasoning* groups), despite showing poor levels of accuracy and speed overall, were more consistent in the way they read the orthographic words than phonological equivalents. They were significantly more accurate when reading orthographic analogy items than when reading the phonological primes, suggesting that these children were using the orthographic information implicit in the clue word to identify unfamiliar target words. This, furthermore, suggests that children in the lowest clusters were in fact more efficient in solving orthographic analogies than the children with the more able profiles. The findings also indicate that children's use of orthographic analogies in word reading may not be associated with increases in reading proficiency and early phonological awareness; rather the ability to make true orthographic analogies based on shared orthographic spelling patterns between words depends on the child's limited knowledge of the reading domain. The results suggest that apparent increases in phonological awareness and reading proficiency may be associated with an increased use of phonological priming rather than an increased use of orthographic analogy.

The suggestion that young children make orthographic analogies when their reading skills and phonological knowledge are still very limited is difficult to explain within existing theoretical models of reading development (Goswami, 1993; Goswami & Bryant, 1990). This finding also challenges previous theoretical claims of a strong positive association between advances in phonological skills and increases in

orthographic analogy (Goswami, 1993; Goswami & Bryant, 1990; Muter *et al.*, 1994; Walton, 1995; Wood, 1999, 2000, 2002; Wood & Farrington-Flint, 2002). The findings suggest that phonologically-skilled children may be over-generalising a heuristic that they have discovered in which they guess the correct reading of unknown words by means of a purely phonological strategy, based on rime, that appears to ‘work’ in the context of clue-word type tasks. In contrast, less phonologically skilled children appear to be relying more heavily on their alphabetic knowledge and on assessing the orthographic consistency between words. Their relative lack of phonological fluency has not yet enabled them to discover the potential of the phonologically based guessing strategy.

An important implication of the present findings is that considering individual differences within beginning readers may lead to a more detailed description of children’s analogy development. Identifying patterns in children’s use of orthographic and phonological relations in reading raises the possibility that analogies based on phonological sounds are an important pathway to reading that develops together, or independently to, the use of visual orthographic-based analogies. As with the explanations of the findings in Study 1, the findings from this study also suggest that aspects of both Goswami’s and Bowey *et al.*’s argument is correct and valid: children are using a varying combination of orthographic relations and phonological relations as a route to developing appropriate reading skills. The current profiles do illustrate the possible dangers of focussing either on orthographic analogy accounts of reading (Goswami, 1993) or focussing solely on supporting the phonological priming explanation (Bowey *et al.*, 1998; Goswami, 1999c; Nation *et al.*, 2001; Roberts & McDougall, 2003; Savage & Stuart, 1998, 2001) because aspects of both may be important in children’s natural development in learning to read. To allow for a further examination of the appropriate skills and strategies that underlie reading performance, it is important to pay equal consideration to

children's ability to use orthographic and phonological relations in early word reading.

Relations between general forms of analogical reasoning skill and domain-specific analogising in early reading were examined in this study. A relationship between general reasoning and orthographic analogy use has been reported in at least one previous study (Wood, 1999). Wood's findings indicated that visual reasoning ability was a significant unique concurrent predictor of orthographic analogy use in beginning reading and raised the possibility that other forms of traditional analogical reasoning skills may be related to the use of orthographic analogies in reading. This claim was supported. In the present analyses, it was found that children's performance on the visual analogical reasoning task could predict analogy scores on the Reading Analogy Task, although this effect was not particularly strong. This pattern of results did not extend to children's performance on the causal or thematic reasoning tasks. This relationship between visual analogy and orthographic analogies may relate to children's ability to recognise visual patterns across both types of task. Children's success in reading by analogy depends on their sensitivity to orthographic similarity and their developing phonological awareness. It is this ability to recognise visual patterns, including the proportion of shared spelling patterns between words, that could explain why the two tasks are related (see Goswami, 1998, 1999b). This finding, therefore, would suggest that teaching children more general types of visual analogical reasoning skills might assist in their development of orthographic analogies within the context of reading, although this needs confirmation.

If children's sensitivity to visual similarity accounts for the relationship between general reasoning skills and the use of orthographic and phonological relations in beginning reading, then this kind of general visual reasoning ability should be able to explain patterns of individual differences in early orthographic and phonological analogies. However, the discriminant function analysis showed that this claim was unsupported. After dividing children into groups according to the efficiency

in which they used orthographic and phonological relations, group membership was not predicted by their visual analogy skills. This finding seems to suggest that, when looking specifically at different subgroups of children each of which display different levels of reasoning skills, the use of analogy skills in early reading are perhaps more indicative of domain-specific knowledge rather than a sub-component of a generalised analogical reasoning skill. The poor relations between reading analogies and traditional reasoning skills, as highlighted in the discriminant function analysis, addresses educational concerns that teaching children general forms of analogical reasoning skills may not help development in specific domains like reading. Instead, teaching children about principles underlying the reading domain itself (e.g., phonological skills) may lead to a more refined use of analogical reasoning within the domain.

However, perhaps an important limitation with this study is its failure to measure individual strategy choices in reading. As discussed in Chapter 2, it is possible that children are not consistently applying their knowledge of relations to read the analogy items presented in the Reading Analogy Task but instead using alternative strategies to aid their reading development. There is no guarantee that children were using an orthographic analogy strategy in the orthographic condition and a phonological strategy in the phonological condition. It is important to establish which of these strategies children report using in each of these conditions and whether they are used consistently throughout the task. Accordingly, in Study 4, a more detailed examination of children's individual strategy choice is carried out using indices of children's self-reports.

In summary, the results support the usefulness of exploring individual differences in children's analogical reasoning skills and demonstrate how early phonological skills play a crucial role in explaining individual differences in children's reasoning abilities (Goswami, 1993, 1999a; Goswami & Bryant, 1990). More specifically, the findings highlight the importance of both orthographic and phonological reasoning

skills as useful strategies in early word reading. Patterns of individual differences in analogy scores show that whilst some children analogise orthographically, others use phonological priming. The extent to which children use either an orthographic or phonological analogy strategy can be best explained by their pre-existing knowledge of the reading domain and more importantly their sensitivity to phonological units in early reading. Any differences in the patterns of knowledge displayed by individual children or subgroups of children can be explained by children's pre-existing knowledge of the reading domain.

Central to this thesis, is the claim that it is important to examine children's analogical reasoning skills across different educational contexts, specifically reading and addition. Although Studies 1 and 2 have shown that young children are able to make analogies in the context of reading, less is known about children's use of analogies within the context of addition. Therefore, Study 3 was designed to examine the salience of analogy in relation to children's addition and to provide a useful framework for making direct comparisons in children's analogical reasoning skills across the two educational contexts.

CHAPTER SEVEN

STUDY 3: ANALOGICAL REASONING IN CHILDREN'S ADDITION

7. Introduction

The purpose of Study 3 was to explore children's analogical reasoning skills in the context of addition. It was argued in Chapter 3, that new research methodologies are needed in order to study relational reasoning in addition more explicitly by looking at children's approaches to analogical problems and to identify the extent to which children use their knowledge of one problem as a basis to solve related problems. Accordingly, in Study 3, the existing conceptual tasks within addition research are framed so that the analogical component is measured and then relations between this analogical component and performance on other traditional forms of analogical reasoning, as well as addition problem solving skills, are examined.

As discussed in Chapter 3, understanding early addition, like understanding all mathematics, is about looking for and recognising relations. Previous researchers interested in children's understanding of early addition concepts have tended to explore children's ability to recognise, explain and use relations between pairs of problems (Baroody, 1987; Baroody & Gannon, 1984; Baroody *et al.*, 1983; Canobi, 2004; Canobi *et al.*, 1998, 2002, 2003; Putnam *et al.*, 1990). Unfortunately, although using one's knowledge of a related addition problem to solve a new problem is an example of analogical reasoning, researchers have tended to ignore the potential role of analogies in early addition. Current conceptual knowledge tasks (e.g. Canobi *et al.*, 1998, 2002) provide an indirect measure of analogical reasoning ability. Some conceptual knowledge tasks have been concerned with measuring children's ability to judge and explain problem

relations rather than examining whether they can solve related problems by analogy. In other types of tasks children are not presented with an initial problem and answer that is identifiable as the target for the analogy. Instead, they are required to spontaneously notice problem relations between related pairs interspersed with randomly ordered pairs (e.g. Canobi, 2004; Canobi *et al.*, 1998). As with the Reading Analogy Task, in order to explore analogical reasoning more explicitly, children need to have a clearly identifiable base problem to provide them with a basis for making the analogy. This base problem should remain in view during the trial to allow each child to refer back to the initial problem and specific prompts and instructions should be provided to inform children that they could use the previous problem as a basis for solving related problems.

A central goal of Study 3 was to assess children's ability to use analogies based on commutativity and additive composition-type relations. To make an analogy between two addition problems, the child must be able to infer the answer to a problem with reference to a similar problem that is related by a key concept (e.g., commutativity, $2 + 3$ and $3 + 2$). To achieve this, children must be able to recognise the relational similarity between addition problems and apply their conceptual knowledge to solve a series of related problems. If young children already have some understanding of relational knowledge (e.g., knowledge of addition principles) then they should be able to apply this knowledge as a basis for solving conceptually related problems in addition.

A further aim of Study 3 was to examine relations between analogical reasoning and domain-specific problem solving skills. Given that researchers have tended not to provide a direct measure of analogical skills within addition, it is unclear whether addition problem solving is related to analogical reasoning within the context of addition. It is suggested that mathematical concepts guide and constrain problem solving (Gelman & Gallistel, 1978; Gelman & Greeno, 1989; Resnick, 1992, 1994; Resnick & Ford, 1981; Resnick & Omanson 1987) although the precise way in which this might

occur requires further research attention. More specifically, there have been claims that children's conceptual understanding of commutativity precedes their use of advanced counting principles, such as counting-on from the larger addend (Cowan & Renton, 1996) and that the use of advanced counting principles reflects commutativity-type knowledge (Baroody *et al.*, 1983; Canobi *et al.*, 1998, 2002; Groen & Resnick, 1977; Resnick & Ford, 1981). However, it is necessary to specify exactly how analogical reasoning skills relate to addition problem solving.

Furthermore, Study 3 examined age related changes in children's addition-based analogical reasoning skills. There is an extensive literature documenting how children's addition problem solving skills improve with age. In particular, addition research shows that older children solve problems more quickly and accurately and use more advanced strategies than younger children (Ashcraft & Fierman, 1982; Boulton-Lewis & Tait, 1994; Canobi *et al.*, 2002; Carpenter & Moser, 1984; Geary & Brown, 1991; Geary, Brown, & Samaranayake, 1991; Goldman, Mertz, & Pellegrino, 1989; Siegler, 1987, 1989). However, there has not been consistent evidence that children's knowledge of principle-based relations between problems improves with age. For example, Canobi *et al.* (2002; 2003) found school children's addition problem solving improves with age but, despite its relationship with problem solving, knowledge of addition principles did not improve with age. However Langford (1981) and Bermejo and Rodriguez (1993) found evidence for age effects in children's understanding of relations based on addition principles such as commutativity and associativity. Moreover, research into analogical development in domains other than addition also suggest that as they get older, children develop a more refined and detailed use of analogical reasoning skills to solve unfamiliar target problems (Gentner, 1983, 1989; Halford, 1992). However, given the lack of research examining analogies within addition, it is currently unknown how children's ability to use analogies within addition is related to their age and experience. Thus, possible relations

between analogical reasoning within addition and age need further investigation.

Finally, similar to Study 2, Study 3 was designed to investigate whether more general forms of analogical reasoning abilities are related to children's use of analogy within addition. As noted in Chapter 1, at present, little is known whether analogical reasoning about principle-based relationships is based solely on domain-specific concepts, such as mathematical knowledge, or whether it is based on other forms of analogical reasoning ability. This is an important question for children's cognitive development as it addresses current controversy in the literature: that is claims that such principles are developed on the basis of domain-specific concepts (Gallistel & Gelman, 1990; Gelman & Greeno, 1989). Conversely, it addresses claims that the development of analogical reasoning reflects the development of a reasoning skill that is general and influences reasoning across more specific domains (Goswami, 1996; Vosniadou, 1989).

This research was designed to address three specific hypotheses. First, on the basis of previous studies that show a developmental progression in young children's understanding of addition concepts (Canobi, 2004; Canobi *et al.*, 1998, 2002, 2003; Close & Murtagh, 1986; Langford, 1981), it was expected that children would use analogies based on commutativity more frequently than analogies based on additive composition. Second, it was hypothesised that a strong relationship between children's use of analogies within addition and their profiles of addition problem solving would emerge, independent of age. Third, it was hypothesised that children's performance on more traditional forms of analogical reasoning tasks would predict their performance on tasks that require the use of analogies to solve addition problems.

7.1. Method

7.1.1. Participants

Sixty-six children (31 males, 35 females) participated in the study. Forty-two children were in Year 1 and twenty-four children were in Year 2 grades. The children were selected from two schools in Nottinghamshire, UK and were tested at the beginning of the academic year. The total sample had a mean chronological age of 6 years 2 months ($SD = 8$ months). Children in Year 1 had a mean chronological age of 5 years 10 months ($SD = 3$ months) and children in Year 2 had a mean chronological age of 6 years 10 months ($SD = 4$ months). Early mathematical ability was assessed using the British Ability Scales II single number concepts sub-test and the mean mathematical age of the sample was 94.08 ($SD = 7.11$). The age groups were selected on the basis of pilot testing indicating that the tasks were of a suitable level of difficulty for children of this age. All children spoke English as their first language. Parents gave full informed consent to their child's participation.

7.1.2. Initial Pre-Test and Screening

All children in the two schools were in year-one and year-two classes ($n = 141$) and were assessed to determine their level of mathematical proficiency using the British Ability Scales II number concepts sub-test. This measures children's early number recognition and mathematical problem solving on both addition and subtraction problems. Only those children who could demonstrate some mathematical understanding, both in terms of recognising single and multi-digit numbers and solving simple addition problems were selected ($n = 66$). This ensured that children began the study with similar levels of competence in mathematics. (Pilot testing revealed that children in reception classes were unsuitable to take part in the study, as their addition knowledge was not sufficiently

developed to allow them to take part in the experimental tasks).

7.1.3. Materials

7.1.3.1. Number Concepts

The number skills sub-test was taken from the British Ability Scales II and was included to provide a baseline measure of children's early number and arithmetical skills (Elliot *et al.*, 1996). This consists of items designed to assess children's early number recognition, and their ability to solve addition problems, subtraction problems and multiplication problems. The trials become progressively more difficult and children are required to answer three or more problems correctly in any one trial to continue. The Number Skills sub-test was administered individually to each child.

7.1.3.2. Traditional Analogical Reasoning Measures

The same series of traditional analogical reasoning tasks as used previously in Study 2 were included in the present study to provide a measure of children's analogical reasoning skills (based on familiar causal, thematic and visual relations). The three tasks used the same experimental procedure but varied in terms of the types of relations that children were required to use (see Appendix G, Figures 1, 2 & 3). These tasks were presented on a computer laptop, which allowed sensitive measures of accuracy and speed to be recorded. (The speed and accuracy scores were adjusted to take into account the different number of choices available on each of the three reasoning tasks. These scores were weighted by multiplying the scores obtained (out of 10) by the total number of choices available).

a. The causal reasoning task. The causal reasoning task assessed young children's ability to use knowledge of physical causal relations (such as 'melting' or 'cutting'), as a basis for completing analogies in the form of *bread is*

to sliced bread as apple is to sliced apple (Goswami, 1989a). This task comprised 10 trials. In each trial, children were presented with a sequence of three pictures (e.g., *bread, sliced bread* and *apple*). Children selected their answer from four alternatives, the correct alternative (e.g., slice of bread) or a wrong object correct physical change (e.g., slice of cake), correct object, wrong physical change (e.g., bruised apple), mere appearance match (e.g., ball). One point was scored for each correct trial.

b. The thematic reasoning task. The thematic reasoning task assessed young children's ability to use their knowledge of thematic relations (such as 'lives in', 'wears') to complete analogies in the form of *gloves are to hands as shoes are to feet* (Goswami & Brown, 1990). This task comprised 10 trials. In each trial, children were presented with a sequence of three pictures (e.g., *gloves, hands, shoes*). Children selected their answer from one of four alternatives, the correct answer (e.g., feet), a strong thematic associate (e.g., socks); a category match (e.g., boots), or a mere appearance match (e.g., shoes). One point was scored for each correct trial.

c. The visual reasoning task. The visual reasoning task assessed young children's ability to complete analogies on the basis of shared visual relations (Wood, 1999). This task comprised 10 trials. In each trial, children were asked to look closely at the different shapes, compare them and explain how the shaded part had changed. Children were presented with a sequence of three pictures and selected their answer from five alternatives, the correct answer, correct object-wrong transformation, wrong object-correct transformation; a high similarity match to 'B' inverted, or a mere appearance match. One point was scored for each correct trial.

7.1.3.4. The Addition Analogy Task

The Addition Analogy Task was designed to assess young children's ability to use their understanding of addition principles as a basis for solving related problems by analogy. The task was adapted from one used by Canobi *et al.*, (1998) but, in order to provide a direct measure of analogical reasoning skill, children were told that the initial problem might assist them in solving related problems. Therefore unlike the task employed by Canobi *et al.*, (1998) the present task did not require children to spontaneously employ analogical reasoning when and if they noticed problem relationships. Children were given an explicit target for their analogy by presenting them with an initial problem along with its answer. This precludes the possibility that children who are able to make analogies do not do so because they are unable to find a basis for making the analogy. This clue remained in view throughout the trial to allow each child to refer back to the initial problem whilst attempting to solve the target problem. No time limit was imposed which prevented excluding those children who were found to be slow in responding to the problems.

The task comprised 32 related problems: 16 two-term and 16 three-term addition problems (e.g., $2 + 5$ and $2 + 4 + 6$) interspersed with 32 unrelated problems. The related problems were based on commutativity and additive composition relationships where the initial problem and its solution could be used as a clue to solving the subsequent problem. Specifically, in the commutativity problems, the second problem included the same addends as the first, but in a different order (e.g., the sum $3 + 2$ was immediately preceded by $2 + 3$ or the sum $4 + 3 + 5$ was immediately preceded by $5 + 4 + 3$). The additive composition problems involved either decomposing one of the terms of an immediately preceding two-term problem to form a three-term problem (e.g., $9 + 2$ followed by $3 + 6 + 2$) or adding the first two-terms of an immediately preceding three-term problem to form a two-term problem (e.g., $7 + 4 + 5$ followed by $7 + 9$). The remaining set of

unrelated control problems consisted of an initial problem and its solution followed by an unrelated problem that could not be solved by analogy (see Appendix D). (According to the formal definition of the principle, associativity should be assessed in terms of decomposing and recombining problems in order to solve related problems, however, pilot testing revealed that many 5 and 6 year-old children were unable to recognise and solve these kinds of problems so they were not included in the present research program).

A computer version of the task was devised to provide a sensitive measure of the accuracy, speed and individual self-reported procedures. Initially, a clue problem appeared in the centre of a 22.5 computer screen and children were given the answer to this initial problem. The experimenter hit a timing key to present a new target problem and children are asked to solve this target problem. The clue problem remained in view, which enabled the child to refer back to the relational pattern of numbers in that problem and to use this clue as a basis for solving the target problem. The interviewer hit a key when children started their answers in order to record solution times. (Preliminary testing revealed that although a voice activated timing system was the most accurate way to record solution times, this was often unreliable given that many of the children often computed aloud, see Canobi et al; 1998, 2003). After children gave their answers to each problem, the interviewer asked how they worked out the problem and these self-reports of the procedures the children described were recorded individually. After each child's reports were recorded, the interviewer hit a key to present the following problem. The order of presentation of the related and unrelated analogy problems were completely randomised across trials and across children. For each clue problem there were four corresponding target problems:

- i. Commutativity type analogy.* Commutativity problems were designed to assess children's ability to make analogies on commutativity (e.g., '4 + 9' and '9 + 4').

ii. Additive composition type analogy. Additive composition problems were designed to assess children's ability to make analogies on aspects of the additive composition principle (e.g., '4 + 9' and '4 + 3 + 6').

iii. Commutativity control problems. Commutativity control problems were included as an equivalent control for the commutativity problems and shared at least one addend in common with the clue problem (e.g., '4 + 9' and '6 + 9').

iv. Additive composition control problems. Additive composition control problems were included as an equivalent control for the additive composition problems and shared at least one addend in common with the clue (e.g., '4 + 9' and '4 + 5 + 3').

7.1.4. Coding Self-Reports

Children's self-reports were coded according to the scheme employed in previous addition studies (Canobi *et al.*, 1998, 2002, 2003). Children were credited with using retrieval strategies when they stated that they simply knew the answer (Canobi *et al.*, 1998). Strategies were coded as decomposition when children reported deriving their answer to a problem from another problem (e.g., for $5 + 6$: "I know that $5 + 5 = 10$, so $5 + 6$ must be 11."). Strategies were coded as counting-all when children reported starting counting at 1 and counting-on when children reported counting from an addend either with or without using their fingers. Children were credited with using analogies to solve related problems when they reported solving the target problem on the basis of the preceding problem. Specifically, strategies were coded as commutativity when children reported that the order of the addends was reversed and coded as additive composition when they recognised that the numbers could be additively combined or decomposed in various ways. The accuracy and speed of each procedure was recorded individually.

7.1.5. General Procedure

Each child was interviewed individually on two separate occasions. Children completed the British Ability Scales II number skills sub-test and the thematic, causal and proportional reasoning tasks in the first 30-minute session. This was designed to provide a baseline score of children's number skill and an accurate measure of their analogical reasoning skill, respectively. The Addition Analogy Task was presented in a second 30-minute session. Sessions were between one and three days apart. Within each session, the order in which the tasks were presented was counterbalanced across participants.

7.2. Results

The results are presented in three parts. The first addresses the salience of analogical reasoning skills and the possibility of an ordering in the use of key concepts for making analogies within children's addition. In the second part, distinct patterns of addition problem solving are identified as a basis for exploring relations between children's use of analogy within addition, their profiles of problem solving strategies and their age group. Third, relations between children's use of analogies within addition and their traditional analogical reasoning skills and age is examined.

7.2.1. Analogies in Addition

The goal of the first set of analyses was to examine the salience of analogy in children's addition by investigating children's ability to make analogies to solve conceptually related problems. In particular, the research was designed to explore the possibility that the children were more accurate in making analogies based on knowledge analogous to commutativity than additive composition. If children perform better in the analogy conditions than in the unrelated control conditions, then this suggests that

children are using the similarities between the clue problem and target problem to solve the second problem by analogy.

The means and standard deviations for accuracy and solution times are summarised in Table 7.1. The data was analysed using a one-way repeated measures analysis of variance to examine differences in performance across the conditions. In the accuracy analyses, the main effect of condition was significant, by-subjects: $F(3, 65) = 12.42, p < .001, \eta^2 = .160$; by-items: $F(3, 60) = 3.57, p < .05, \eta^2 = .151$, suggesting that children's ability to detect and use analogies varied across the different conditions. Planned comparisons revealed that the commutativity problems were solved more frequently than the equivalent controls, by-subjects: $t(65) = 4.54, p < .001$; by-items: $t(30) = 2.80, p < .01$, and that commutativity problems were solved more frequently than additive composition problems, by-subjects: $t(65) = 4.45, p < .001$; by-items: $t(30) = 2.68, p < .05$. However, there was little difference in children's performance on the additive composition problems and their equivalent controls, by-subjects: $t(65) = 0.47, p > .05$; by-items: $t(31) = .20, p > .05$, suggesting that children did not appreciate the relationship between clue and target problem therefore finding it difficult to make analogies based on additive composition.

In support of the accuracy data, the main effect of condition based on solution times were significant, by-subjects: $F(3, 65) = 36.51, p < .001, \eta^2 = .360$; by-items: $F(3, 60) = 10.77, p < .001, \eta^2 = .350$, indicating that children varied in the speed of their responses across the different conditions. (Analyses only included individual solution times of less than 60 seconds and excluded incorrect responses). Planned comparisons revealed that children were quicker at solving commutativity problems than equivalent controls, by-subjects: $t(65) = 7.54, p < .001$; by-items, $t(30) = 4.55, p < .001$ and quicker at solving commutativity problems than additive composition problems, by-subjects, $t(65) = 6.50, p < .001$; by-items, $t(30) = 4.61, p < .001$. However, the analyses also revealed

that children were no quicker in solving additive composition problems than the equivalent controls, by-subjects, $t(65) = .55, p > .05$; by-items, $t(30) = .80, p > .05$.

In devising the stimuli, a number of *decoy problems* were included to investigate the possibility that children were simply looking for the same numbers as in target problems without considering fully the conceptual relations and using the analogy strategy to solve the related addition problems. The decoy problems shared either one or two numbers in common with the initial clue problem (e.g., $9 + 8$ and $2 + 8$). Analyses showed that children were more proficient in solving the order analogy problems than equivalent decoy problems both in terms of the frequency of correct responses ($t(65) = 5.84, p < .001$) and solution time ($t(65) = 7.64, p < .001$). However, there was no difference between the speed and accuracy on the additive composition problems and the equivalent decoys (p 's $> .05$). This suggests that the children either may not have been fully appreciating the shared relational structure between additive composition problems or alternatively, they may have been using additive composition-based concepts to solve the decoy problems as well as the composition-type analogy problems.

Table 7. 1

Mean Accuracy, Solution Time (and Standard Deviations) for Problems in the Addition Analogy Task

Problem type ^a	2 term problems		3 term problems	
	Accuracy	Speed	Accuracy	Speed
Commutativity	6.39 (1.81)	7.02 (5.03)	5.94 (2.01)	11.05 (6.35)
Commutativity controls	4.95 (2.43)	10.72 (5.18)	5.44 (2.07)	13.24 (5.47)
Additive composition	5.68 (2.04)	11.26 (5.11)	5.05 (2.28)	14.62 (8.50)
Additive composition controls	6.05 (1.82)	10.66 (5.85)	4.94 (2.26)	14.16 (6.40)

^a Maximum score in each condition was 8 (standard deviations in parentheses).

Solution-time in seconds (analyses includes individual solution time of less than 60 seconds and includes correct responses only).

A key question was whether children were reporting that they were aware that the commutativity principle could be used to solve the conceptually related addition problems. In order to examine whether children were using their knowledge of relations to solve analogical problems correctly, the percentage frequency and speed of children's individual reported strategies in solving the related problems was examined next.

The purpose of this stage of the analyses was to explore whether children are able to apply their understanding of relations as a basis for solving analogical problems in addition (see Table 7.2). For problems solved correctly, for each child, the percentage of times she/he reported using a particular problem solving strategy was calculated using the following formula: Number of problems solved correctly using each particular strategy divided by the total number of problems solved correctly then multiplied by 100 to give a percentage score. The first column of figures in Table 7.2 shows the mean percentage use of the various strategies by all children according to problem type. This column shows that on average children reported using Count on and Commutativity more often than other strategies although there was quite wide variation in the use of these strategies. Count all was the next most common strategy reported. Percentage use of all other reported strategies was minimal. The next column of Table 7.2 shows the percentage of children who reported using the various strategies at least once to solve the various problems correctly. For both two and three-term related problems 83 percent of children reported using a Count on strategy at least once suggesting that this was a strategy that was readily available to the majority of children. The next frequently reported strategy was Commutativity. For the two term problems, 65 percent of children reported using Commutativity at least once and for the three term problems, 61 percent of children reported using Commutativity to solve the related problems at least once. However, although Count on was the most commonly used strategy, it was relatively inefficient compared with Commutativity. When children used Count on as a strategy,

solution times on average were three times longer than when they used Commutativity to solve the problems (see Table 7.2). This was true for both two and three-term problems. (Based on the self-reports in Table 7.2, children very seldom applied analogy to additive composition measures on the two-term and three-term problems so these scores are not analysed further. As the use of this strategy based on additive composition was used so infrequently, it is not possible to examine patterns across the two types of analogy using cluster analysis).

Table 7.2

Means (and Standard Deviations) for individual children's percentage strategy use, percentage of children who used particular strategies at least once and mean solution times (in seconds) associated with each strategy for correctly solved related problems.

Self reported strategies	% strategy use	% strategy users	Speed
Two-term related problems			
Commutativity	34 (29)	65	3.65 (1.10)
Additive composition	1 (6)	9	5.76 (2.07)
Retrieval	3 (6)	29	4.50 (1.43)
Decomposition	4 (10)	21	8.11 (5.68)
Count on	36 (20)	83	10.44 (4.65)
Count all	20 (31)	44	13.46 (5.07)
Mixed ^a	1 (2)	8	7.89 (4.86)
Three-term related problems			
Commutativity	27 (6)	61	5.35 (2.05)
Additive composition	4 (9)	20	8.34 (5.10)
Decomposition	1 (4)	8	11.98 (4.03)
Count on	47 (38)	83	15.26 (8.46)
Count all	19 (30)	42	17.12 (6.45)
Mixed ^a	2 (6)	17	14.94 (10.11)

^a Mixed strategies included a combination of more than one individual strategy.

7.2.2. Patterns of Problem Solving, Addition Analogies and Age

The goal of this second set of analyses was to identify patterns of domain-specific problem solving in order to explore whether children's use of analogy to solve commuted problems was related to their profiles of domain-specific problem solving skills and age.

However, before analysing profiles of addition problem solving, the research explored the frequency and speed associated with individual children's self-reported strategies on solving the unrelated addition problems (see Table 7.3). For the total number of unrelated problems solved correctly, for each child, the percentage of times she/he reported using a particular problem solving strategy was calculated. The first column of figures in Table 7.3 shows the mean percentage use of the various strategies by all children according to problem type. As shown in Table 7.3, children often reported using various strategies to solve the unrelated problems including retrieval, decomposition, counting-all, counting-on and a combination of mixed strategies. The next column of Table 7.3 shows the percentage of children who reported using the various strategies at least once to solve the various problems correctly. For both two and three-term unrelated problems, children reported using retrieval and decomposition infrequently and reported using back-up strategies such as counting-on and counting-all more often. Children reported using counting-on more frequently than counting-all. The time taken also varied depending on whether children reported using retrieval, decomposition or counting strategies. While reported retrieval and decomposition were associated with fast solution times; children's reports of using counting-on and counting-all were typically slower (c.f. Canobi *et al.*, 1998, 2002, 2003). Children also responded more quickly when using counting-on than counting-all.

Table 7. 3

Means (and Standard Deviations) for individual children's percentage strategy use, percentage of children who used particular strategies at least once and mean solution times (in seconds) associated with each strategy for correctly solved unrelated problems.

Problem solving strategies	% strategy use	% strategy users	Speed
Two-term unrelated problems			
Retrieval	6 (9)	47	5.38 (2.12)
Decomposition	6 (16)	21	6.37 (2.64)
Count on	66 (48)	86	11.09 (5.62)
Count all	21 (30)	47	14.72 (6.75)
Mixed ^a	1 (3)	3	6.55 (0.95)
Three-term unrelated problems			
Retrieval	1 (2)	2	9.30 (0)
Decomposition	1 (2)	6	11.32 (3.21)
Count on	70 (51)	83	13.49 (5.07)
Count all	24 (37)	40	16.29 (4.38)
Mixed ^a	4 (10)	23	11.20 (5.85)

^a Mixed strategies included a combination of more than one individual strategy.

A cluster analysis was used to characterise individual differences in children's addition problem solving skills (c.f. Canobi *et al.*, 1998, 2002, 2003; Siegler, 1988a). To identify patterns of addition problem solving, Ward's clustering algorithm was applied to the total number of unrelated problems solved correctly, the speed of these correct responses and the number of times children reported using retrieval, decomposition, counting-on and counting-all. (Standardised scores were used). A 4-cluster solution, which accounted for 63% of the total variance in children overall accuracy, and the speed and accuracy of self-reported procedures, was selected (see Table 7.4).

The *flexible-strategy* group ($n = 6$) often reported using retrieval, decomposition and counting-on and showed high levels of accuracy in solving the unrelated addition problems. The *counting-on* group ($n = 33$) reported using decomposition and retrieval less frequently than those in the *flexible-strategy* group and relied mainly on counting-on. Although they were above average in terms of their accuracy and speed, the counting-on group were less efficient than the *flexible-strategy* group in terms of their ability to solve problems correctly. The *counting-all* group ($n = 11$) were less accurate and consistently slower than the previous clusters relying on counting-all as their primary strategy. The *least accurate-strategy* group ($n = 16$) were very slow and inaccurate and relied almost exclusively on less sophisticated procedures, such as counting-on and counting-all to solve the unrelated control problems. It is likely that the adoption of less sophisticated strategies often led to incorrect responses overall (Canobi *et al.*, 1998).

An analysis of covariance was conducted to examine whether analogical reasoning within addition was related to children's profiles of addition problem solving after taking age into account (see Table 7.5). In keeping with previous studies of addition principles (Canobi *et al.*, 1998, 2003), there was a strong relationship between analogical reasoning and addition problem solving even after controlling for age, $F(3, 61) = 4.17, p < 0.01, \eta^2 = .170$. Planned comparisons showed that children with higher levels of

problem solving sophistication (*flexible strategy, counting-on* group) tended to use analogies based on commutativity to solve related problems more frequently than the less sophisticated problem solving group (*least accurate strategy* group) ($p < .05$). There was a linear relationship between age and addition problem solving showing that, in keeping with previous research older children tended to use more sophisticated problem solving procedures (Ashcraft & Fierman, 1982; Boulton-Lewis & Tait, 1994; Canobi *et al.*, 2002; Carpenter & Moser, 1984; Geary & Brown, 1991; Geary *et al.*, 1991; Goldman *et al.*, 1989; Siegler, 1987, 1989). However, there was no relationship between chronological age and analogical reasoning in addition, $F(1, 61) = 3.21, p > .05$.

Table 7. 4

Means (and Standard Deviations) for the Accuracy, Speed and Frequency of Self-Report Procedures as a Function of Problem Solving Cluster

	Problem solving cluster			
	Flexible-strategy	Counting-on	Counting-all	Least accurate
Overall accuracy ^a	26.00 (1.26)	25.82 (3.91)	21.00 (9.52)	10.75 (4.61)
Overall solution time ^b	13.09 (3.60)	16.18 (5.21)	19.89 (3.87)	26.41 (9.62)
Retrieval	1.33 (1.03)	1.03 (1.08)	0.82 (0.98)	0
Decomposition	4.83 (3.20)	0.52 (0.97)	0.18 (0.41)	0.06 (0.25)
Counting-all	0	0.64 (1.37)	15.18 (7.47)	7.69 (6.10)
Counting-on	16.33 (1.37)	23.36 (4.13)	4.64 (4.41)	3.00 (3.46)
Mixed strategies	3.50 (1.38)	0.21 (0.49)	0.18 (0.41)	0
<i>n</i>	6	33	11	16

^a Total number of unrelated problems solved correctly. ^b Solution time in seconds for the unrelated control problems solved correctly.

Table 7.5

Means (and Standard Deviations) of Children's Age and their Reported use of Commutativity as a Function of Problem Solving

<i>Cluster</i>	Addition problem solving cluster			
	Flexible strategy	Count on	Count all	Low accuracy
Age (in months)	80.83 (4.96)	76.15 (7.06)	73.27 (6.53)	70.06 (3.53)
Addition relations (commutativity)	12.67 (2.810)	8.58 (5.86)	7.36 (5.97)	2.06 (4.40)
<i>n</i>	6	33	11	16

7.2.3. Analogies in Addition and Traditional Reasoning Skills

The goal of the third set of analyses was to examine whether children's performance on the thematic, causal and visual analogy reasoning tasks could predict their performance on using analogy (commutativity) to solve addition problems using fixed order stepwise regression analysis. Examining relations between measures of this analogical component of mathematical thinking and other forms of reasoning is important in order to evaluate claims that the ability to reason in addition is based on domain-specific knowledge (Gelman, 1998; Gelman & Gallistel, 1978; Resnick, 1992, 1994). The fixed-order stepwise regression examined the extent to which children's traditional analogical reasoning scores could predict their performance on the addition analogy problems (see Table 7.6). Age and number concepts were entered into the regression model at steps 1 and 2. Thematic, causal and visual reasoning scores were entered into the model at steps 3, 4 and 5. The results showed that when age was entered first into the model, it could account for over 16% of the overall variance in addition analogy. When entered next into the model, children's understanding of number concepts could explain an additional 5% of the variance after age was taken into account. However, children's performance on thematic, causal and visual reasoning tasks did not account for any significant amount of variance in addition analogy. Although it is worthy of note that of the three traditional analogical reasoning tasks, performance on the visual reasoning task consistently accounted for 3% of the variance regardless of which regression model was adopted.

Table 7.6

Fixed Order Regression with Reported Commutativity Score as the Dependent Variable and Traditional Analogical Reasoning Scores as Predictors

Steps 1 to 5	R ²	R ² Change	F value
Step 1: Age (in months)	.165	.165	12.693**
Step 2: BAS II number concepts	.217	.051	4.115*
Step 3: Thematic relations	.220	.003	.271
Step 4: Causal relations	.231	.011	.843
Step 5: Visual relations	.262	.031	2.543
Revised ordering			
Step 3: Visual relations	.251	.034	2.841
Step 4: Thematic relations	.253	.002	.170
Step 5: Causal relations	.262	.009	.724
Revised ordering			
Step 3: Causal relations	.227	.011	.853
Step 4: Visual relations	.260	.033	2.684
Step 5: Thematic relations	.262	.002	.172

Note. * p < .05, ** p < .01

7.3. Discussion

The purpose of the study was to examine the salience of analogies in addition and furthermore to assess whether this form of reasoning is related to domain specific problem solving and to other traditional forms of analogical reasoning skills. Two of the three hypotheses proposed in the study were supported by the data. First, children were able to make analogies based on commutativity and additive composition (although analogies based on additive composition-type relations were less frequent). Second, a strong relationship between children's use of addition analogies and their profiles of addition problem solving emerged, independent of age. Specifically, children with the more sophisticated addition skills profiles, who reported using retrieval, decomposition and advanced counting strategies, reported solving analogical problems based on commutativity more frequently than the other children. Third, children's performance on the traditional form of analogical reasoning tasks did not, however, appear to predict the success they had in using analogies in the context of addition.

In keeping with previous research indicating that many children as young as five years of age understand additive commutativity (Baroody & Gannon, 1984; Bermejo & Rodriguez, 1993; Canobi *et al.*, 1998, 2002, 2003; Cowan & Renton, 1996; Langford, 1981; Sophian *et al.*, 1995a), and additive composition (Baroody, Wilkins, & Tiilikainen, 2003; Martins-Mourao & Cowan, 1998), the current study has also shown that children are able to use these principles as a basis for making analogies to solve addition problems. When the tasks are structured in a way that investigates analogy use explicitly, it is apparent that young children do use analogies in addition (but only for some types of conceptual relations). The possible educational implications of this finding is that explicitly teaching children to look for shared conceptual relations between addition problems may help in developing their addition knowledge and improving their addition problem solving skill. It is clear that analogy skills are important in

children's addition and that children were more accurate on making analogies based on those problems that reflected the principle of commutativity compared to problems that reflected additive composition type relationships. Similar findings emerged on the basis of solution times, which revealed that children were generally quicker at responding to order problems than composition problems. Children's performance on the Addition Analogy Task suggests that they were more proficient in recognising that numbers can be added in different orders than recognising that numbers can be decomposed and recombined in different ways (see Canobi *et al.*, 1998, 2003). This finding suggests a possible theoretical account of addition development with an early use of analogical reasoning to solve commutativity type problems leading to a later use analogical reasoning to solve additive composition type problems.

Study 3 also explored relations between analogies in addition and domain specific problem solving strategies. The ability to make analogies between conceptually related addition problems was related to distinct profiles of addition problem solving reflecting qualitative differences in the speed, accuracy and choice of problem solving procedures. The problem solving profiles revealed that one group, the *flexible-strategy* group, were very accurate and quick at solving the addition problems and used a combination of mental arithmetic, decomposition and counting-on. In keeping with previous studies, (Canobi *et al.*, 1998, 2002, 2003), the present results reveal that children who frequently reported using commutativity as a strategy for solving analogically-related problems tended to show this flexible and sophisticated pattern of addition problem solving skill. Another group, the *counting-on* group, were less efficient in solving composition-type addition problems and tended to rely on counting-on as their main strategy. By comparison, a third group, the *counting-all* group, were less efficient in their problem solving and tended to rely on counting-all to compute answers. The fourth group, the *least accurate* group, were very poor in their problem solving skills and often

relied on less advanced counting-strategies to compute the answers, although this often led them to give incorrect answers.

Overall, the analyses showed that those children who were least efficient in making analogies based on commutativity also showed less sophisticated patterns of problem solving procedures. Conversely, those children who frequently reported using analogies more consistently in addition also reported high levels of decomposition, retrieval, and counting-on to solve the unrelated addition problems correctly. The findings suggest that the ability to make analogies within addition is grounded on the same types of domain specific skills and principles that children call upon to solve addition problems quickly and accurately. Moreover, the identification of meaningful profiles of problem solving ability and the uncovering of a relationship between these profiles and children's ability to use addition analogies strengthens the claim that exploring patterns of individual differences often leads to a more complete understanding of early arithmetical development (Canobi, 2004; Canobi *et al.*, 2003; Dowker, 1998).

As expected, patterns of problem solving were also associated with age (see also Canobi, 2004; Canobi *et al.*, 2002, 2003). Older children solve addition problems more quickly and accurately, retrieving more answers from memory and using less concrete counting strategies than younger children. The identification of different profiles of problem solving sophistication led to the discovery that older children had more advanced problem solving profiles than younger children (Ashcraft & Fierman, 1982; Boulton-Lewis & Tait, 1994; Canobi *et al.*, 2002; Carpenter & Moser, 1984; Geary & Brown, 1991; Geary *et al.*, 1991; Goldman *et al.*, 1989; Siegler, 1987, 1989). With age and experience, children will develop from using less sophisticated procedures, including counting-all to more sophisticated and efficient procedures like the use of advanced counting procedures, retrieval and decomposition (Canobi *et al.*, 1998, 2003).

The present study revealed, however, that children's ability to reason analogically in addition was independent of age (see Canobi, 2004; Canobi *et al.*, 1998). One possible reason for this finding is that age-related effects in analogy skills are outside the age range studied. That is, analogical reasoning may be a strategy that is available from relatively early within a child's mathematical development. The finding that analogies within addition are independent of age is furthermore supported by claims that relational reasoning is achieved very early in development (Goswami, 1996, 2001a) and that children develop an early appreciation for addition relations, e.g., commutativity (Canobi *et al.*, 1998, 2002, 2003; Sophian *et al.*, 1995a; Sophian *et al.*, 1995b).

One possible reason for the finding that the ability to reason analogically about addition is not related to age is an educational emphasis on promoting successful problem solving before conceptual understanding (analogical reasoning) (see also Canobi, 2004). The present findings suggest that children might benefit from direct instruction that makes explicit the implications of using analogical relationships between problems for problem solving. The 5 year-olds in the study were able to make analogies based on commutativity-relations, which demonstrates their ability to solve conceptually related problems using their knowledge of domain-relevant principles such as commutativity. With formal tuition, experience in solving addition problems and a better understanding of addition concepts, it is possible that children will come to learn the benefits of making analogies between conceptually related problems in addition.

The study also examined the extent to which children's performance on traditional forms of analogical reasoning tasks was related to their ability to solve addition problems by analogy. The findings revealed that children's performance on traditional tasks of analogical reasoning (based on thematic, causal and visual relations) did not predict their success in making analogies within the context of addition. This finding that traditional reasoning skills cannot contribute to domain specific forms of analogy within

addition suggests that children's domain-related knowledge is the prerequisite for analogical reasoning in addition and not some more general capacity to look for and reason about relations. The poor relations between children's use of addition analogies and their traditional reasoning skills addresses important educational concerns that teaching children general reasoning skills may not help problem solving in specific domains like addition. Instead, teaching children about principles underlying addition itself may lead to a more refined use of analogy within this specific domain.

In summary, the finding that children's use of analogy to solve commuted addition problems was related to their profiles of addition problem solving skill underscores the possibility that using analogical reasoning skills to solve related problems may lead to procedural advances. The results also indicate that the ability to reason by analogy in addition is unrelated to other forms of analogical reasoning. The analyses revealed that analogical reasoning skills outside the context of addition have very little influence on children's use of analogy in addition. Although the present results do not indicate a significant relationship between analogical skills outside the context of addition and addition analogies, nevertheless, the next strongest predictor after age and pre-existing domain knowledge had been taken into account was visual reasoning ability. In order to rule out such a relationship completely, however, it would be necessary to systematically examine analogical reasoning across a series of different contexts or domains to address possible commonalities in children's reasoning abilities. Accordingly, in Study 4, the consistency in children's analogical performance in both addition and reading using tasks that require children to reason about relations within these two domains was explored. Comparing children's ability to use analogical reasoning skills in these two domains will further address the possibility of a domain general analogical component underlying children's knowledge of reading and addition. This may also illustrate links or

commonalities in children's analogical reasoning performance in each of these two separate educational domains when examined together.

CHAPTER EIGHT

STUDY 4: COMPARING CHILDREN'S USE OF ANALOGY IN READING AND ADDITION

8. Introduction

The purpose of Study 4 was to examine possible similarities in the way children use analogies in reading and addition by looking for differences in the patterns of knowledge displayed by individual children or subgroups of children. Studies 2 and 3 showed that young children could use analogies as a strategy to aid their reading and addition activities. Given that children demonstrate some ability to reason by analogy in each of these two different contexts when measured independently, the next goal was to explore whether there are any links or commonalities in children's use of analogies across the two contexts when measured together. To achieve this, the consistency with which children reported using different strategies in solving analogical problems in reading and addition was measured using indices based on speed and accuracy for each individual self-reported strategy. Study 4 also examined whether distinct patterns of responses could be identified using the accuracy associated with the different strategies that children report using in the reading and addition tasks.

To provide a more detailed characterisation of whether there are any links between children's analogical reasoning skills across the reading and mathematics domains, it is important to make direct comparisons of the same children's performance in both the reading and addition tasks together. The reading and addition analogy tasks used in Studies 2 and 3 are similar both in terms of the structural design of the tasks and the analogical component underlying each task. Therefore, the number of trials included in each task, the total number of problems presented and number of conditions were

controlled systematically. Given the difficulties that children had in making analogies based on additive composition in Study 3, these were not included in the present study. In Study 4, the research included three different conditions corresponding to one analogy condition, one partial similarity control condition and one unrelated control condition. Study 4 specifically set out to explore children's analogy performance in both reading and addition by looking for distinct patterns of analogy skills. It is argued that examining individual differences will provide a detailed understanding of children's educational achievements and capabilities in reading and addition (see Studies 1, 2, & 3).

Study 4 was also designed to focus more closely on children's individual strategy choices in both reading and addition and to examine how these choices impact upon individual differences in their analogical performance on the reading and addition analogy tasks. Individual self-reports of strategies were recorded after the presentation of each problem and the speed and accuracy of the associated strategy was examined independently. This allowed a more detailed analysis of analogical performance within the two domains of reading and mathematics. This enabled Study 4 to address issues concerning the consistency with which children use analogies in reading and addition through the use of retrospective verbal protocols (see Siegler, 1987, 1989). Although in Study 2, distinct patterns in analogy skills were identified revealing qualitatively different pathways to reading success, this study did not use self-reports to identify the strategies children may have been using to read the target words in the Reading Analogy Task. It still remains unclear, therefore, whether children's success on this task actually reflects their ability to strategically use analogies or whether they are using a combination of alternative strategies as well as using analogical relationships. In Study 3, however, verbal self-reports of strategies were examined and this proved to provide a clear and precise method of exploring the wide repertoire of strategies children use to solve simple addition problems. The possibility of identifying variability in children's strategy

choice in reading, however, has not previously been examined. Therefore, in order to examine whether children are consistently applying analogical reasoning strategies to solve the analogical problems, they were asked to verbally report the types of strategies they have used after the presentation of each target problem in both the reading and addition tasks. On the basis of findings from Study 3, and previous research (Siegler, 1987, 1988a, 1989), it is reasonable to suggest that children will not always use the most prominent strategy to solve analogical problems in either reading or addition and that they will report using a variety of different strategies in both contexts.

As argued in Chapter 3, identifying patterns in early reasoning abilities will provide a detailed understanding regarding the diversity and complexity of children's developmental profiles in the domains of reading and addition. Using measures of reported strategies also enriches the data, because it is possible to characterise children's performance on the basis of the speed and accuracy of their different strategies, rather than focussing solely on accuracy scores alone. It also allows further confirmation about the precise strategies that children are using on each of the two analogy tasks and whether the same children who are using analogy strategies in reading are also those who report using analogy-based strategies in addition. It is important to establish whether children's analogical reasoning is limited to either reading or addition or alternatively whether they demonstrate equivalent levels of analogical performance in both domains when measured together.

The present study was designed to address five specific hypotheses. First, it was hypothesised that young children would make analogies in the context of reading and that they will use a wide repertoire of strategies in reading to solve the related analogy problems. Addressing this question allows the research to examine how consistently young children are applying their knowledge of conceptual relations to solve analogical problems in reading and to replicate the findings of Study 2. Second, on the

basis of Study 3 and previous findings (Canobi *et al.*, 1998, 2003; Siegler, 1987, 1988b), it was hypothesised that the children would report using a wide repertoire of strategies for solving the analogy problems in addition including counting procedures, retrieval, decomposition and using analogical relationships. Third, in line with domain general theorists (e.g. Inhelder & Piaget, 1958; Piaget *et al.*, 1977), it was predicted that if analogical reasoning strategies are important for children's development in different educational domains, then analogical reasoning within one specific context would concurrently predict analogical reasoning within the other context. Fourth, on the basis of findings from Studies 2 and 3, it was hypothesised that distinct patterns of analogy based on individual strategy choices across the context of reading and addition would emerge. Fifth, again based on the findings reported in Chapters 6 and 7, it was expected that children's pre-existing domain knowledge, specifically single word reading, vocabulary and number concept understanding, might be able to explain these patterns of reasoning skills across reading and addition.

8.1. Method

8.1.1. Participants

Sixty-nine children (31 boys, 38 girls) participated in the study. The children were selected from three schools in Nottinghamshire and two schools in Milton Keynes, UK and were tested in May and June towards the end of the academic year. They had a mean chronological age of 5 years 8 months ($SD = 6$ months). The age groups were selected on the basis of pilot testing indicating that the revised tasks used in this study were of a suitable level of difficulty for the children. The mean ability score of the children on the British Ability Scales II single word reading sub-test was 92.41 ($SD = 5.52$) and the mean ability score on the British Ability Scales II number concepts sub-test was 103.04 ($SD =$

8.87). The mean score of the group on the British Picture Vocabulary Scales II was also within normal limits for the sample (Mean = 98.59, $SD = 11.57$). All children spoke English as their first language. Parents gave written informed consent to their child's participation.

8.1.2. Initial Pre-test and Screening

The same screening criteria were used in the present study as found in Studies 1, 2 and 3. Initial pre-test and screening was required because it was necessary to only include children who were at the early stages of learning about reading and addition. The children who participated in this study were all in reception and year-one classes ($n = 208$) and were recruited through three stages. First, single word reading ability was assessed using the British Ability Scales II single word reading test to establish their emergent reading ability. Second, children were pre-tested on their ability to read the non-word items that would later be used in the Reading Analogy Task. All children had to demonstrate initial reading ability, but only those children who were unable to read any of the words in the Reading Analogy Task were selected ($n = 79$). Third, children's mathematical ability was assessed using the British Ability Scales II number concepts sub-test. Only those children who could demonstrate some mathematical understanding, both in terms of recognising single and multi-digit numbers and solving simple addition problems were selected ($n = 69$). Similar to Studies 2 and 3, this screening process ensured that all children began the study with the same levels of competence in reading and addition.

8.1.3. Materials

8.1.3.1. Receptive Vocabulary

The British Picture Vocabulary Scales II is a measure of receptive vocabulary, which required children to identify pictures that correspond to words spoken by the

experimenter (Dunn *et al.*, 1997). The words become progressively more difficult and children are required to continue until they were correct on only four words out of a set of twelve items. The child's raw score was then converted to a standardised score for the purpose of analysis.

8.1.3.2. Single Word Reading

The single word-reading sub-test was taken from the British Ability Scales II and included to provide an early baseline measure of children's single word reading ability (Elliot *et al.*, 1996). The words become progressively more difficult and children are required to answer eight or more words correctly in any one trial to continue. The child's raw reading score was then converted to a standardised score for the purpose of analysis.

8.1.3.3. Number Concepts

The number concepts sub-test was taken from the British Ability Scales II and was included to provide a baseline measure of the children's early number and arithmetical skills (Elliot *et al.*, 1996). This consisted of items designed to assess children's early number recognition, and their ability to solve addition problems, subtraction problems and multiplication problems. The trials become progressively more difficult and the children are required to answer three or more problems correctly in any one trial to continue. The Number Skills sub-test was administered individually to each child. The children's raw reading scores were converted to standardised scores for purpose of analysis.

8.1. The Reading Analogy Task

The Reading Analogy Task used in Study 4 was a revised version of the task used previously in Studies 1 and 2. This task explored children's propensity to notice how the

spelling-sound pattern of one non-word can be used as a basis for working out the spelling-sound pattern of other similar non-words. This version of the task also included additional measures of the accuracy and speed of children's reported strategy choices. As in Study 2, the clue word appeared in the centre of a 22.5cm screen and children were told its pronunciation and told that this clue-word might help them to read other non-words. The experimenter hit a timing key to present a new target word and children were asked if they are able to read this particular target word. The original clue word remained in view, so that the child could refer back to the spelling pattern of the clue word. The interviewer hit a key when children stated their answers in order to record solution times.

As with Study 2 two sets of unfamiliar non-word items were devised to control for the effects associated with high word frequency and unintentional intra-list priming. The Reading Analogy Task comprised of sixteen clue words. Unlike Study 2, however, the number of conditions was reduced to include only one analogy condition and two control conditions. For each clue word, there were three target words corresponding to one of the following:

- i The orthographic rime analogy.* These non-words shared a common phonological rime and orthographic ending with the clue (e.g., 'keyl' - 'leyl').
- ii The partial similarity controls.* These non-words shared a common phonological rime with the clue, but share a different orthographic pattern (e.g., 'keyl' - 'yail').
- iii The unrelated controls.* These non-words shared no common phonological or orthographic overlap with the clue so the use of analogy would lead to an incorrect answer (e.g., 'keyl' - 'gamp').

8.1.3.5. The Addition Analogy Task

The Addition Analogy Task was similar to the task used in Study 3. It was included

to assess young children's ability to use their understanding of commutativity as a basis for solving analogical problems. As before, children were given an explicit target for their analogy by presenting them with an initial problem along with its answer. This clue remained in view throughout the trial to allow each child to refer back to the initial problem. No time limit was imposed.

However, only commutativity-based problems were included in this study given the poor levels of responding to additive composition problems found in Study 3. As with Study 3, a clue problem appeared in the centre of a 22.5 computer screen and children were given the answer to this initial problem. The experimenter hit a timing key to present a new target problem and children were asked to solve this target problem. The clue problem remained in view, so that the child could refer back to the relational pattern of numbers in that problem and to use this clue as a basis for making an analogy. The interviewer hit a key when children stated their answers in order to record individual solution times. After children solved each problem, the interviewer asked how they worked out the problem and recorded the speed and accuracy of each child's self-reported strategy for that problem. After each child's reports were recorded, the interviewer hit a key to present the following addition problem.

Unlike Study 3, the task comprised sixteen related two-term addition problems and thirty-two unrelated problems. The related problems were based on the principle of commutativity (e.g., $2 + 5$ and $5 + 2$). The orders of presentation of the related and unrelated analogy problems were completely randomised across tasks and across children. For each of the clue problems there were three target problems corresponding to one of the following:

- i. The Commutativity analogy.* The items were related to the clue problem in terms of the commutativity principle and were designed to assess children's

understanding that numbers can be reversed but remain the same

(e.g., $2 + 3$ and $3 + 2$).

ii. The partial similarity controls. These items shared either one or two numbers in common with the clue problem and were included to detect whether children were looking for the same numbers in target problems without considering the conceptual relations (e.g., $2 + 3$ and $2 + 5$).

iii. The unrelated controls. These items shared no similarity with the clue problems and could not be solved using an analogical reasoning strategy (e.g., $2 + 3$ and $4 + 5$).

8.1.4. Coding

To provide a more detailed account of children's individual strategies, the speed and accuracy of individual self-reports of strategy choices were recorded on both the reading and addition analogy tasks.

8.1.4.1. Reading Strategies

The following coding framework was devised for explicitly studying children's individual strategy choices in reading. During their performance on the Reading Analogy Task, children were credited with using retrieval strategies when they stated that they simply knew the answer. Children were credited with using sounding-out when they reported identifying each individual phoneme and sounding them out and blending the sounds together. Strategies were coded as retrieval and sounding out when children reported knowing part of the word and used sounding out to generate the remaining phonemes of that particular word. Children were credited with using orthographic analogy strategy when they reported using the visual similarity with the clue word as a basis for working out the spelling-sound structure of the new word.

8.1.4.2. Addition Strategies

Canobi et al's (1998) framework for coding children's self-reports on the Addition Analogy Task was adopted in the present study. This was the same framework used in Study 3. Children were credited with using mental arithmetic (retrieval/guess) strategies when they stated that they simply knew the answer (Canobi *et al.*, 1998). Children were credited with using decomposition when they reported deriving their answer to a problem from another problem (e.g., for $5 + 6$: "I know that $5 + 5 = 10$, so $5 + 6$ must be 11."). Strategies were coded as counting-all when children reported starting counting at 1 and counting-on when children reported counting from an addend either with or without using their fingers. Children were credited with using relations to solve related problems when they spontaneously reported solving them based on their relations with preceding problems. They were credited with solving commuted problems by analogy when they reported that the order of the addends was reversed with reference to the clue problem.

8.1.5. General Procedure

Each child was interviewed individually on three separate occasions. Children completed the British Ability Scales II number concepts sub-test, the single word reading sub-test and the British Picture Vocabulary II vocabulary test in the first 30-minute session. The first part of the Addition Analogy Task and the Reading Analogy Task was presented in a second 20-minute session. The third 20-minute session comprised of part two of the Addition Analogy Task and the Reading Analogy Task. Overall, sessions were between one and three days apart and within each session, the order in which the tasks were presented was counterbalanced across participants.

8.2. Results

The results are presented in five parts. In the first part, the salience of analogies in children's early reading is explored to try and replicate previous findings in Studies 1 and 2. The analyses also examine whether children report using a wide variety of alternative strategies in both the Reading Analogy Task. In the second part, the salience of analogies in children's addition is examined to replicate the findings from Study 3 and to examine variability in children's reported strategies. In the third part, the possibility that analogical reasoning in one domain could predict analogical reasoning in another domain is examined using regression analysis. In the fourth part, individual differences in children's analogical performance in reading and addition is explored using cluster analysis. In the fifth part, the contribution of age and domain knowledge to patterns of performance across the two tasks (i.e. reading and addition) is examined.

8.2.1. Analogies in Reading

The goal of the first set of analyses was to explore children's performance on the different conditions in the Reading Analogy Task to replicate the findings from Studies 1 and 2. If children perform better in the analogy condition than in the partial similarity or unrelated control conditions, then this suggests that children are using the similarities between the clue word and target word to read unfamiliar words by analogy.

The data were examined using one-way analysis of variance. The experimental design consisted of a one within-subject factor, condition. Table 8.1 summarises the mean scores and standard deviations for the speed and accuracy of children's scores according to the different conditions for reading and addition. Cronbach's alpha reliability coefficients for each condition in the analogy tasks are provided.

In the accuracy analyses, the results showed a main effect for condition, by-subjects: $F(2, 68) = 146.61, p < .001, \eta^2 = .683$; by-items: $F(2, 45) = 133.35, p <$

.001, $\eta^2 = .856$. Planned comparisons revealed, both by-subjects and by-items, that orthographic analogy words were read more frequently than the partial similarity controls, by-subjects: $t(68) = 5.51, p < .001$; by-items: $t(30) = 3.50, p < .01$, and more accurate in reading the orthographic analogy words than unrelated controls, by-subjects: $t(68) = 15.48, p < .001$; by-items: $t(30) = 15.67, p < .001$.

To explore whether different patterns of problem solving emerge on the basis of children's individual solution times, a second analysis of variance was conducted. (Analyses only included individual solution times of less than 60 seconds and excluded incorrect responses). Similar to Study 2, the solution time results showed a different pattern of results to the accuracy data. By-subjects the solution time analyses failed to show any significant main effect for condition, $F(2, 68) = .315, p > .05, \eta^2 = .005$, although this was significant by-items, $F(2, 45) = 4.96, p < .05, \eta^2 = .180$. Planned comparisons, by-items, showed that the children were no quicker at reading orthographic analogy words than partial similarity controls, $t(30) = 1.38, p > .05$, but they were more efficient in reading the orthographic analogy words than the unrelated controls, $t(30) = 2.24, p < .05$. The results support those found in Study 2.

Table 8.1

Means (and Standard Deviations) for the Accuracy and Speed of Children’s Performance on each Condition in the Reading and Addition Analogy Tasks

Conditions ^a	Accuracy	Speed ^b	α
Reading Analogy Task			
Orthographic analogy	9.09 (3.82)	5.13 (3.14)	0.79
Partial similarity controls	7.33 (4.17)	4.91 (3.09)	0.83
Unrelated controls	1.64 (1.72)	5.30 (5.41)	0.56
Addition Analogy Task			
Commutativity analogy	10.38 (4.94)	8.45 (6.01)	0.92
Partial similarity controls	6.97 (3.89)	13.97 (5.47)	0.83
Unrelated controls	5.74 (4.31)	12.33 (6.35)	0.89

^a Maximum score in each condition = 16.

^b Solution-time in seconds (analyses include correct responses only).

The frequency and speed associated with children’s self-reported strategies was examined. Children often used more than one strategy to solve the analogy problems in the Reading Analogy Task. Indeed, 32% of children used one strategy whereas 52% used two, 13% used three or more. Table 8.2 shows the children used four main strategies on the Reading Analogy Task, including, sounding out, orthographic analogy, a combination of ‘mixed’ strategies and guessing. For problems solved correctly, for each child, the percentage of times she/he reported using a particular problem solving strategy was calculated using the following formula: Number problems solved correctly using a particular strategy divided by the total number of problems solved correctly multiplied by 100. This gave a percent frequency for each individual strategy. The first column of

figures in Table 8.2 shows the mean percentage use of the various strategies by all children according to problem type. This column shows that on average children reported using analogies and sounding-out more often than other strategies although there was quite wide variation in the use of these strategies. Percentage use of all other reported strategies was minimal. The next column of Table 8.2 shows the percentage of children who reported using the various strategies at least once to solve the various problems correctly. For the related problems on the Reading Analogy Task, 87 percent of children reported using an analogy strategy at least once suggesting that this was a strategy that was readily available to the majority of children. The next most frequently reported strategy was sounding out at 67%. This was also true with respect to solution times. Analogies were associated with fast solution times, although when children used sounding-out as a strategy, solution times on average were almost twice as long than when they used analogies to solve the problems, (see Table 8.2).

Table 8.2

Means (and Standard Deviations) for individual children's percentage strategy use, percentage of children who used particular strategies at least once and mean solution times (in seconds) associated with each strategy for correctly solved related problems.

Self-reported procedures	% strategy use	% strategy users	Speed
Reading Analogy Task			
Reading analogy	75 (52)	87	4.38 (2.82)
Sounding-out	21 (24)	67	7.56 (4.37)
Mixed strategies ^a	1 (3)	7	5.19 (3.82)
Guessing	3 (7)	20	2.61 (0.90)
Addition Analogy Task			
Addition analogy	65 (58)	65	3.48 (0.95)
Retrieval	2 (4)	19	3.93 (2.05)
Counting-on (min)	10 (24)	29	11.39 (3.81)
Counting-on (large)	2 (7)	13	13.38 (5.80)
Counting-all	20 (26)	87	15.97 (5.03)
Guessing	1 (5)	10	3.51 (1.90)

^a Mixed strategies included a combination of more than one individual strategy.

8.2.2. Analogies in Addition

The goal of this second set of analyses was to explore children's performance on the different conditions in the Addition Analogy Task in order to replicate the findings from Study 3. If children perform better in the analogy conditions than in the partial similarity or unrelated control conditions, then this suggests that children are using the similarities between the clue problem and target problem to solve the second problem by analogy.

The data were analysed using a one-way analysis of variance and the experimental design consisted of one within-subject factor design, condition. In the accuracy analyses, the main effect of analogy type was significant, by-subjects: $F(3, 68) = 58.89, p < .001, \eta^2 = .464$; by-items: $F(2, 45) = 15.43, p < .001, \eta^2 = .407$. Planned comparisons revealed that the commutativity analogy problems were solved more frequently than the partial similarity controls, by-subjects: $t(68) = 6.99, p < .001$; by-items: $t(30) = 4.28, p < .001$, and more frequently than the unrelated controls, by-subjects: $t(68) = 8.94, p < .001$; by-items: $t(30) = 5.52, p < .001$.

In the solution time analyses, a similar pattern of results emerged to the accuracy analyses. The main effect of analogy type was significant, by-subjects: $F(2, 68) = 29.82, p < .001, \eta^2 = .305$; by-items: $F(2, 45) = 84.09, p < .05, \eta^2 = .789$. Planned comparisons revealed that the children were quicker at solving commutativity analogy problems than partial similarity controls, by-subjects: $t(68) = 7.73, p < .001$; by-items, $t(30) = 12.41, p < .01$, and in solving the analogy problems than the unrelated controls, by-subjects: $t(68) = 4.45, p < .001$; by-items $t(30) = 11.78, p < .001$. The results support those found previously in Study 3.

As before, the speed and accuracy associated with children's self-reported strategies for solving the related addition problems were examined (see Table 8.2). This is particularly important as previous research has shown that children tend to use a range of strategies when solving addition problems, ranging from the least

sophisticated, such as counting-all to the more sophisticated such as counting-on and decomposition and those capable of using more advanced strategy may not do so (1998; Canobi *et al.*, 2003; Siegler, 1987; Siegler & Jenkins, 1989). As with Study 3, the speed and accuracy of children's reported strategies varied according to the type of strategy used. Children's use of analogical reasoning strategies and retrieving the correct answer from memory were associated with fast solution times whilst counting-on and counting-all were typically much slower.

8.2.3. Analogical Reasoning across Domains

The goal of this third set of analyses was to examine the extent to which children's use of analogy in one specific domain can predict analogical performance in the other domain. The research explored whether the explicit use of an orthographic analogy strategy in reading can predict the use of analogy in addition using stepwise regression (see Tables 8.3 and 8.4). Only the accuracy scores associated with children's self-reported use of analogy were included.

The first fixed-order stepwise regression examined the extent to which children's ability to solve analogies within the context of addition could predict their analogical performance in reading. The orthographic rime self-report analogy scores were treated as the dependent variable with the self-report addition analogy scores as predictors. Age was entered into the regression models at step 1 to control for the effects of chronological age. Single word reading ability, number concepts and BPVS II scores were entered into the model at steps 2 to 4 to control for the effects of reading ability, mathematical understanding and vocabulary skill. Scores from the Addition Analogy Task was entered in step 5. The results are reported in Table 8.3. As reported for Studies 1 and 2, the ability to make analogies in reading was unrelated to age. However, when entered in Step 4, vocabulary could account for 6% of the shared variance in reading analogy after the other

baseline measures had been controlled. Moreover, children's self reported analogy scores in addition explained an additional 8% of the observed variance in reading analogy after accounting for performance on the baseline measures.

Given the strength of this prediction and the possibility that the use of analogy in addition can facilitate analogical reasoning in the reading domain, a second fixed-order stepwise regression was carried out to explore the possibility that children's self-reported analogy scores in reading could also predict children's ability to reason analogically in addition (see Table 8.4). As hypothesised, a similar pattern of results emerged to the first model, revealing that children's scores on the Reading Analogy Task could explain a unique proportion of the variance in reported use of analogy in addition. However, unlike the previous model, when entered first into the regression model, age was found to account for 15 % of the overall variance in addition analogy. Similar to before, when entered in Step 4 of the regression model, vocabulary could account for an additional 7% of the variance in addition analogy. However, reading analogy scores could explain another 7 % of the observed variance in analogy scores in addition, after the contribution of single word reading, number concepts and receptive vocabulary was taken into account. These analyses suggest that the use of analogy in one specific domain can provide a concurrent prediction of analogical reasoning ability in another specific domain, although this is not a particularly strong predictor. Nevertheless, the findings do lend some support to suggestions that a child who displays analogical reasoning in one domain will also show this type of reasoning in other unrelated domains.

Table 8.3

Fixed-Order Regression with Age, Pre-Existing Domain Knowledge and Self-Reports of Analogy in Addition as Predictors

Dependent variable: reading analogy scores			
Steps 1 to 5	R ²	R ² Change	F value
Step 1: Age (in months)	.149	.149	3.599
Step 2: Single word reading	.100	.049	3.570
Step 3: Number concepts	.104	.004	.299
Step 4: Receptive vocabulary	.166	.063	4.812*
Step 5: Addition analogy	.207	.080	6.701*

Note. * p < .05 ** p < .01

Table 8.4

Fixed-Order Regression with Age, Pre-Existing Domain Knowledge and Self-Reports of Analogy in Reading as Predictors

Dependent variable: addition analogy scores			
Steps 1 to 5	R ²	R ² Change	F value
Step 1: Age (in months)	.149	.149	11.690**
Step 2: Single reading ability	.160	.012	.935
Step 3: Number concepts	.167	.007	.525
Step 4: Receptive vocabulary	.238	.070	5.906*
Step 5: Reading analogy	.311	.073	6.701*

Note. * p < .05 ** p < .01

8.2.4. Patterns of Strategy Choices across Domains

The previous section has demonstrated that the use of analogy within one domain can predict the use of analogies within another, whether this relates to reading or addition. The shared variance across the two domains is a particularly important finding because it suggests that analogical reasoning is not completely domain-specific, instead the results suggest there may be some considerable overlap in children’s analogical reasoning in both reading and addition. The next set of analyses examined whether any similarities in children’s patterns of reasoning skills across the two domains could be identified using an analytical clustering technique. Analysing accuracy scores across a range of indices will provide a more detailed understanding of individual differences in analogical reasoning skills that might apply across domains.

To examine whether it was possible to identify distinct patterns of reasoning skills across the two tasks of reading and addition, Wards clustering algorithm was applied to the total number of problems that children solved correctly in each analogy condition using the self-report strategies identified in Table 8.2. (The order of frequency of reported strategies in the reading task were; reading analogy, sounding-out, and mixed strategies. The order of frequencies for reported strategies in the addition task were; addition analogy, counting procedures, retrieval and mixed strategies). Children's self-reports of guessing were not entered into the cluster analysis because this did not qualify as a legitimate strategy.

A five-cluster solution, which accounted for 90% of the total variance in children's reported strategies, was selected. Children in the *high general reasoning* group ($n = 18$) reported using analogy strategies consistently across the different trials and achieved high levels of accuracy in both the reading and addition tasks, with a slight, although not significant, advantage for reported use of analogy within addition. Children in the *intermediate general reasoning* group ($n = 5$) were less accurate in using analogies across the two domains. Although both the *high general reasoning* group and the *intermediate general reasoning* group showed equivalent levels of analogising across the two domains, the main distinction is that the *intermediate reasoning* group were less accurate overall and reported using strategies other than analogy. Children in the *low reasoning* group ($n = 40$) displayed almost equivalent levels of analogical reasoning in the both reading and addition tasks, however, their levels of accuracy were poor overall. Children in this group showed that they were able to use analogies in reading and addition but not accurately. Although these children relied solely on analogies in addition, they were beginning to use alternative strategies in reading, which included analogies and sounding-out. The *reading reasoning* group ($n = 4$) showed a distinct advantage for reporting the use of analogies in reading but not addition. Although these four children used analogy

consistently in reading, they reported the use of analogy less frequently in addition, relying more on counting-procedures. In contrast, the *addition reasoning* group ($n = 2$) reported high levels of analogy in solving addition problems, however, they relied less often on using analogies within reading. In fact, the performance of those children on the reading task was characterised by self-reports of using analogy and grapheme-phoneme correspondences (e.g., sounding-out and blending together individual phonemes) to solve the related analogy words.

Table 8.5

Means (and Standard Deviations) for the Accuracy of Reported Strategies in the Reading and Addition Tasks as a Function of Cluster

Reported strategies	Reading and addition cluster			
	High reasoning	Intermediate reasoning	Low reasoning	Reading reasoning Addition reasoning
Reading analogy task				
Reading analogy	10.00 (2.59)	8.60 (5.03)	5.07 (4.46)	8.00 (7.17) 5.00 (7.07)
Sounding-out	0.89 (1.08)	1.40 (2.07)	2.35 (2.13)	1.75 (2.87) 5.00 (5.66)
Mixed strategies	0 (0)	1.00 (0)	0 (0)	0 (0) 0 (0)
Addition analogy task				
Addition analogy	13.44 (1.92)	8.20 (7.53)	3.78 (5.15)	1.50 (3.00) 12.00 (1.41)
Retrieval	0 (0)	.20 (.45)	.20 (.41)	.50 (.58) 1.00 (0)
Counting strategies	.25 (.27)	.80 (1.11)	.90 (.71)	2.94 (.66) .13 (.18)
Mixed strategies	0 (0)	0 (0)	0 (0)	0 (0) 1.00 (0)
<i>n</i>	18	5	40	4 2

8.2.5. Explaining Patterns of Strategy Choice

The cluster analysis identified different patterns of responses, or subgroups of children, according to the efficiency they demonstrate in solving conceptually related problems in the contexts of reading and addition. It is now important to consider possible differences between the five clusters in more detail by comparing each of these clusters against standardised measures of single word reading, receptive vocabulary, number concepts understanding and age. The standardised scores on each of these tests for each of the five clusters are provided in Table 8.6. (Due to the small number of children in two of the five clusters it was not feasible to run inferential statistics to test for possible differences, see Tabachnick & Fidell, 2001).

However, looking at children's standardised scores across the five distinct groups does provide an indication that there may be some form of developmental trend occurring. Table 8.6 shows that the children in the *low reasoning* group had the lowest scores on the single word reading and number concepts tests and was some of the youngest children in the sample. Children in the *intermediate reasoning* group, displayed similar profiles of single word reading and number concepts to the *low reasoning* group, although these children were slightly older. Children in the *high reasoning* group, however, were the oldest children in the sample and had the highest level of receptive vocabulary scores overall. Finally, children in the last remaining two groups, the *reading* and *addition reasoning* groups, are children who reported to have used analogical relationships to solve problems in one domain or the other but not both domains together. These children have higher single word reading scores and number concepts scores than children in the other groups but lower vocabulary scores overall. This finding suggests that higher levels of pre-existing domain knowledge may, in part, be associated with the

children's use of more sophisticated strategies in the reading and addition analogy tasks, and not associated with the use of analogies.

Overall, those children with higher levels of domain knowledge seem to demonstrate a tendency to use analogical reasoning in either one domain or the other but not in both domains together. This finding is particularly interesting because these children in the *reading* and *addition reasoning* groups reported using alternative strategies, other than using analogical relationships to solve the related problems in either addition or reading. In line with the findings from Studies 1, 2, and 3, this suggests that with increases in domain knowledge, and problem solving experience, children begin to discover alternative, more sophisticated strategies in reading and addition and this is reflected in their performance. These findings would seem to suggest, therefore, that whilst analogical reasoning skills are important early in children's development in the context of reading and addition, the ability to use analogical reasoning skills may not necessarily be a developmentally sophisticated skill as previously assumed within the developmental literature (see also Goswami, 1992).

Table 8.6

Means (and Standard Deviations) for Children’s Age and their Pre-Existing Domain Knowledge as a Function of Cluster

Standardised measures ^a	Reading and addition cluster			
	High reasoning	Intermediate reasoning	Low reasoning	Reading reasoning Addition reasoning
Age (in months)	74.56 (5.29)	71.40 (6.54)	68.80 (5.40)	74.00 (4.55) 74.00 (2.83)
Single word reading	90.78 (5.63)	89.80 (7.36)	93.25 (5.10)	93.75 (2.22) 94.00 (12.73)
Number concepts	100.89 (9.79)	106.80 (7.98)	102.10 (8.24)	111.25 (4.03) 115.50 (.71)
Receptive vocabulary	101.94 (12.38)	99.40 (10.99)	98.20 (11.63)	92.25 (4.57) 87.00 (5.66)
<i>n</i>	18	5	40	4 2

^a Standardised scores (Mean = 100, SD = 15)

8.3. Discussion

The purpose of this study was to examine patterns in the various strategies that children use to solve reading and addition-based analogical tasks and to investigate possible commonalities in children's reasoning skills across the two domains. The results suggest that the children demonstrated using a wide repertoire of strategies for correctly solving analogical problems in both reading and addition. Furthermore, the findings also suggest that it is meaningful to characterise children's performance according to the types of strategies they report and to consider the speed and accuracy associated with each of these strategies individually. Children who frequently reported the use of analogy strategies in reading tended also to report using analogy strategies to solve analogical problems in addition. This finding would suggest that children's ability to reason about relations in both reading and addition is linked.

In general, the five hypotheses were supported by the results. First, as hypothesised, young children were more accurate at reading target words in the orthographic analogy condition than in the partial similarity or unrelated control conditions. This performance, however, was accompanied by a wide repertoire of reported strategies suggesting that children did not use the analogical reasoning strategy exclusively to read all the related orthographic analogy words. Second, as hypothesised, children also reported using a wide repertoire of strategies for solving the analogy problems in addition including counting procedures, retrieval, and decomposition as well as using analogical relationships. Third, as expected, children's analogical reasoning in reading could concurrently predict analogical reasoning skills in addition. The effect was the same when the process was reversed whereby analogy scores in addition predicted analogy scores in reading. Fourth, as expected there was evidence of some cross-domain similarities in children's use of

reasoning strategies in reading and addition when examined together. Indeed, distinct individual difference patterns of strategy choice were identified based on the different types of strategies children reported using when solving analogical problems in both reading and addition. Fifth, children's chronological age and their pre-existing domain knowledge could explain differences between the current profiles of reasoning skills.

The findings demonstrate that analogies are extremely salient to children's understanding in both reading and addition. In all of the children identified, the most common strategy children reported using involved analogical reasoning, although the use of this strategy did not necessarily mean that children were able to give the correct answers to the addition and reading problems. As with Studies 1 and 2, children in this study were able to make orthographic analogies in beginning reading based on rime correspondences using non-word items and this orthographic analogy effect remained robust. Also, in keeping with the results found in Study 3, the results showed that these young children were also able to use their understanding of commutativity as a basis for making analogies within addition. The finding that analogies are salient to children's addition also strengthens the claim that when tasks are structured in a way that investigates analogy explicitly, children do frequently report using analogical relationships in a way that appear to be based on their conceptual knowledge of addition principles. Taken together, the possible educational implications of these findings are that teaching children to explicitly look for shared conceptual relations between words (e.g., word reading) or numbers (e.g., simple addition) may help develop their understanding of that particular domain. Although the potential educational implications for the teaching of analogies in early reading has already been addressed in some detail within the reading literature (see Goswami, 1995a; 1999a for a review), the possible educational implications of explicitly encouraging children to use analogical strategies based on

relational similarity to improve their understanding of addition has not been examined previously. The findings, therefore, demonstrate that a more explicit focus on teaching children to use analogical reasoning to reinforce their knowledge of addition concepts is worthwhile.

As expected, children reported using a wide repertoire of strategies in solving the analogy problems in reading. However, unlike previous assumptions made on the basis of average accuracy scores across conditions (e.g., Goswami, 1986, 1988, 1990a, 1990b; 1993), the present findings also illustrate that children are not entirely consistent in their use of analogy. Specifically, rather than strategically applying their knowledge of relations on every trial, children reported using a range of alternative strategies to read the related unfamiliar words on the Reading Analogy Task. This is a particularly important finding although surprising given the salience of analogies in reading and the strong theoretical claims regarding the educational importance of analogies as a basis for teaching young children to read (Goswami, 1998, 1999a, 1999b). The findings also highlight the possible dangers of failing to fully consider variability in children's individual strategy choices in reading tasks. The goal of future research should therefore be to address why children report using a wide repertoire of strategies, children's consistency with using these different strategies, the occasions on which children rely on each particular strategy and how they choose adaptively between different strategies.

As expected, this variability in strategy choice was not limited to children's performance in reading. As with children in Study 3, children in this study reported using a wide repertoire of strategies for solving the analogical problems in the Addition Analogy Task. Unlike their performance on the Reading Analogy Task, however, children reported using analogies more frequently in solving addition analogy problems (42%). The next most common strategy reported were counting procedures (counting-all

and counting-on). The speed and accuracy of these strategies varied, however, suggesting that children found some strategies more effective to use when solving related problems than others. Again, this finding informs researchers about the importance of acknowledging variability in strategy choices (see also Siegler, 1987, 1989).

As argued in Chapter 3, there is a strong tendency to describe development in terms of children consistently using one specific strategy or procedure at any one particular age (see also Siegler, 1996), however, the results from the present study demonstrate that this suggestion is misleading. The findings from this study and previous studies reported clearly demonstrate that children do not always perform in the same way or use the same strategies when solving analogical problems. Instead there is often variation not only across individual children's performance but also within the same child. In this study, children showed considerable variability in the kinds of strategies they choose and despite being able to use analogy strategies to solve some problems, they do not use this strategy on every trial (Siegler, 1996). The verbal self-report procedure used in this study, and in Study 3, illustrates the potential benefits of examining variation in children's individual strategy choices more closely.

In addition to illustrating that children have a wide variety of strategies, Study 4 also revealed important insights into the nature of analogical reasoning across the two specific domains reading and addition. Age was found to be a strong predictor in how well children used analogies in addition which accounted for 15% of the variance when entered first into the regression model (although age was not found to be a strong predictor of performance on the Reading Analogy Task). However, the only unique predictor of children's use of analogy in addition was their reading analogy scores, which accounted for an additional 7% of the variance even after the variance accounted for by age and pre-existing domain knowledge were controlled. This was also true with respect

to children's performance in reading. The regression analyses revealed that children's use of analogical reasoning strategies to solve related addition problems was a strong, unique predictor of their ability to use analogical reasoning strategies in the context of reading, which accounted for 8% after age and domain knowledge were controlled.

While the regression model reveals some similarities across the two domains, however, it does not capture individual differences in children's reasoning skills. Therefore, a cluster analysis was used to identify characteristic patterns in children's performance across the two domains. This analysis led to the identification of five distinct subgroups or clusters. However, sixty-three children from the *low*, *intermediate* and *high reasoning* clusters reported using similar levels of analogical reasoning on both the reading and addition analogy tasks, which suggests a strong domain general analogical component across the two specific domains of knowledge. Aside from these three groups, however, there were a further two groups (i.e., the *reading* and *addition reasoning* groups) consisting of six children who reported to use analogical reasoning strategies on either the Reading Analogy Task or the Addition Analogy Task but not both. This finding is important because it suggests that for the majority of children who participated in this study (although not all), the tendency to use analogies within reading was accompanied by a tendency to use analogies in the context of addition. It is important to note, however, that not all children displayed this pattern of performance. Although those who fell into the smaller clustering groups, relying on the use of analogies in either reading or addition alone could have been overlooked had the decision not been made to consider individual differences in strategy choices. This suggests that some more general analogical reasoning mechanism might underlie the use of analogy in specific domains and therefore requires further consideration. This explanation will be discussed in more detail in the following chapter.

Although cluster analysis does not necessarily provide any specific information regarding developmental changes in children's abilities, it was expected that children's age and their pre-existing domain knowledge might vary according to these profiles. Children's profiles were compared according to their scores on standardised tests of single word reading, number concepts, vocabulary and age, to examine the possibility of identifying developmental profiles. Interestingly, children in the *reading* and *addition reasoning* groups showed higher levels of word reading and mathematical understanding than children in the remaining three groups (the *high*, *intermediate* and *low reasoning* group). These were also among the oldest children in the sample. It is likely that these distinct profiles may hint at possible developmental changes, however, because it was not feasible to run nonparametric analyses with such small sample sizes, a more detailed examination of reasoning skills across different age groups may be useful in order to replicate and strengthen these interpretations.

There are important theoretical and educational reasons for explaining the apparent overlap in strategy choices in reading and addition. Finding strong similarities in children's reported use of analogies in the context of reading and addition raises educational issues concerning the possible benefits of formally teaching analogical reasoning skills to young children and how these skills may then contribute to their ability to solve problems in specific domains like reading and addition. From an educational perspective, the findings suggest that children might benefit from direct instruction that makes explicit the implications of noticing similar analogical relations between problems. However, it is important to note that the present findings do not necessarily illustrate any evidence of spontaneous analogical transfer across the two domains, nor do they suggest that analogical reasoning operates as a domain general mechanism. Instead, the results illustrate possible similarities in children's approach to analogical problems within these

two specific contexts: children who tended to make more analogies in the context of reading were also found to make more analogies in the other context of addition. However, it is important to note that the types of analogy tasks used in the study were deeply embedded within the context of reading and addition, and relied on the children's ability to notice relational similarities between two problems and to use their understanding of domain knowledge to solve the problems correctly. The fact that both the reading and addition analogy tasks were both structurally similar and also shared a similar analogical component, therefore, might account for this observed similarity identified in the present research. The findings demonstrate, nonetheless, that young children might come to learn the benefits of making analogies between conceptually related problems in reading and addition and this might also have implications for identifying similarities across other knowledge domains outside reading and mathematics.

In summary, the findings from Study 4 replicate those of Studies 2 and 3 and show that analogies are particularly important in the development of children's early reading and addition. Using knowledge of relations appears to be a highly salient strategy for children of this age and is clearly important in their development. As noted already, this may have an educational significance with regard to the way in which young children are taught about reading and mathematics in schools. As children report using a wide repertoire of strategies for solving conceptually related problems both in reading and addition and as the speed and accuracy of these strategies varied, it is clear that this developmental trend is not as simple as has been suggested by previous researchers or theories. This will be discussed further in the next chapter.

CHAPTER NINE

CONCLUSIONS AND IMPLICATIONS

9. Introduction

The purpose of the research presented in the thesis was to provide a more detailed examination of the role of analogy in the development of 5 to 6 year-old children's reading and addition. The research was also designed to examine individual differences in children's ability to use analogical reasoning strategies and to identify possible links or commonalities in children's performance in the context of reading and addition. The research program comprised four studies. The findings from the four studies suggest that the use of analogical reasoning skills is important in both reading and addition. The research findings also suggest that there are strong similarities in children's approach to using analogies in reading and addition tasks which raises our awareness to the possible gains that can be achieved by considering children's analogical reasoning strategies across different educational contexts.

The present chapter will consider the conclusions and implications of the present research by reviewing the main research findings and showing how the four studies addressed the research questions presented in Chapter 4. Each of the five questions will be addressed individually and the main conclusions and implications of these findings discussed. Following this, the important theoretical, methodological and educational implications will then be summarised before considering directions for future research.

9.1. Review of the Research Findings

The research was designed to address five specific research questions. First, are there meaningful patterns of individual differences in the kinds of orthographic and phonological relations children use to make analogies in early reading? Second, is the ability to make analogies important to children's knowledge of addition, and furthermore, what is the relationship between children's use of analogy within addition and their domain-specific problem solving skills? Third, to what extent do more traditional forms of analogical reasoning skills contribute to children's ability to make analogies in the domain of reading and addition? Fourth, how consistent are children in applying their knowledge of relations to solve analogical problems within each domain? Fifth, are there any similarities in the way in which young children use analogies in early reading and addition and do distinct patterns of reasoning skills emerge when classifying children's responses across tasks? In the following sections, the theory and research relevant to the five research questions is summarised and the possible theoretical, methodological and educational implications of these findings are then reviewed.

9.1.1. Patterns of Analogy in Beginning Reading

The first research question was concerned with whether it was useful to attempt to identify individual differences in children's ability to use both orthographic and phonological relations as a basis for reading new, unfamiliar words. It was argued in Chapter 2, that findings from previous studies that have averaged data across different age groups to identify developmental trends in early reading ability are seriously flawed. This is because focussing on age-related changes in performance often leads to an oversimplified account of analogy development in reading as differences among individual children are overlooked (Siegler, 1996). Rather than presuming that children of

any given age are all using similar strategies in beginning reading, it is likely that individual children will find their own pathway to reading success and that they will vary according to the extent to which they rely on orthographic or phonological relations to read, to identify new, unfamiliar words. Thus, looking at within-group variability is extremely important. Examining individual differences in children's reasoning is important in order to test existing claims that children show an efficiency in using some phonological relations as a basis for analogy before they use other types of relationships and that analogy use is associated with linear increases in age and experience (Goswami, 1993). Given that Siegler (1996) has identified considerable variation in different children's reasoning profiles both within and across different age groups in other domains of cognitive development, such as addition, it is reasonable to suggest that individual difference patterns would emerge when examining the use of orthographic and phonological relations in beginning readers. An important goal of Study 1, therefore, was to investigate whether different patterns of analogy use emerged when examining the accuracy with which children of the same age were able to use orthographic and phonological relations on the Reading Analogy Task. In order to examine these patterns in reading more closely, Study 2 attempted to replicate the findings of Study 1 using both speed and accuracy measures across a number of different conditions and also explored whether pre-existing domain knowledge, phonological awareness and more traditional forms of analogical reasoning skills contributed to explaining the individual patterns identified in children's early reading performance.

The results of the two studies support the claim that there are strong individual differences in children's development in learning to read. The findings from Studies 1 and 2 indicated that distinct groups could be identified that were characterised by differences in children's patterns of responses to solving different kinds of orthographic and

phonological problems in reading. In Study 1, cluster analysis based on the accuracy of children's responses in using orthographic and phonological relations led to the identification of four distinct groups. One group of children, the orthographic reasoning group, were more accurate in reading the orthographic analogy words than the pure phonological equivalents, suggesting that these children focussed more on the shared orthographic overlap between words and were therefore making genuine rime based orthographic analogies. Another group, the high reasoning group, were highly accurate in reading words in both the orthographic and phonological analogy conditions suggesting that they were using a rhyme based phonological approach, rather than an orthographic approach. A further group, the intermediate reasoning group, showed a similar pattern of results with similar levels of word reading in both the orthographic analogy and phonological analogy conditions but these children were less accurate overall than the high reasoning group. The least sophisticated group, the low reasoning group, were particularly poor in reading words in both the orthographic and phonological conditions which suggests that these children may have been using less accurate strategies that often led to incorrect answers.

In Study 2, more detailed patterns were identified using both the accuracy and speed of children's responses on the Reading Analogy Task. It is important to note that the same four distinct groups were identified for the beginning readers who participated in Study 2 as were found for those who participated in Study 1. Study 2, therefore, strengthens and replicates the findings from Study 1. As with Study 1, the patterns seem to reflect qualitative differences in the extent to which children focus on using either orthographic relations or on purely phonological relations to solve analogical problems in reading. Indeed, children who were found to be accurate in using the orthographic relations between problems were less efficient overall, whereas children who showed equivalent

levels of using both orthographic and phonological relations (which according to Goswami's, 1990a criterion are using a rhyme based phonological approach to reading) tended to display the most successful use of analogy in the sample and also showed considerably higher levels of phonological awareness and reading proficiency overall. This finding is particularly important because, contrary to previous claims (Goswami, 1993, 1999a; Goswami & Bryant, 1990), those children found to be using analogies based on shared orthographic relations alone, and characteristic of making genuine orthographic analogies, were among the least able children in the group (in terms of phonological awareness). Instead, as highlighted in Study 2, increased knowledge of rhyme and phonemes is associated with a phonological strategy, rather than a genuine orthographic analogy route to reading success. This is something that has been overlooked in previous research because the use of traditional analytic techniques, such as the use of regression analysis, does not allow for their identification.

It is argued that identifying patterns of children's responses to solving different forms of analogy problems in reading does provide a more detailed description of children's reading development. The distinct patterns of analogy use illustrates how analogies based on phonological characteristics of the words are an important pathway to reading that might be independent to the use of orthographic analogies. Both Studies 1 and 2 demonstrate how children frequently use a combination of orthographic and phonological relations as a route to identifying unfamiliar words and developing appropriate reading skills. The current profiles illustrate the possible dangers of focussing solely on either orthographic analogy accounts of reading (Goswami, 1993) or solely on phonological priming accounts (Bowey *et al.*, 1998; Goswami, 1999c; Nation *et al.*, 2001; Roberts & McDougall, 2003; Savage & Stuart, 1998, 2001) as aspects of both may be important for different children at different stages in their development. Whilst some

children appear to use relationships based on the visual similarities between clue and target words to make orthographic type analogies, others appear to reason primarily phonologically without any reference to the visual patterns in the clue word. Overall, the findings support the claim that increased attention to variability in children's reading performance (even within the same age group) will provide a stronger basis for a more complete understanding of cognitive development (Siegler, 1996). Indeed, in terms of developing a more detailed theoretical account of reading development, the findings from these two studies suggests that, within particular contexts such as early word reading, children's development is not uniform and stage like, as originally proposed (e.g. Frith, 1985; Marsh, Desberg, & Cooper, 1977; Marsh, Friedman, Welch, & Desberg, 1981).

9.1.2. Analogies in Addition and their Relation to Problem Solving

The second research question was concerned with addressing the importance of analogical reasoning in the development of children's mathematical understanding and the relationship between addition analogies and domain-specific problem solving skills. Given previous evidence regarding a developmental trend in conceptual understanding from an early realisation that numbers can be reordered to a later realisation that numbers can be decomposed and recombined in various ways (Canobi, 2004; Canobi *et al.*, 1998, 2002, 2003), it was expected that children would make analogies based on commutativity relations more frequently than additive composition. It was also expected that children's efficiency in using analogies to solve addition problems would be systematically related to their problem solving sophistication (in particular their reported use of retrieval, decomposition and counting procedures when solving the addition problems that could not be solved by analogy).

The present findings support the claim that analogies are important in children's development of addition knowledge. In Study 3, children were found to be using

analogies based on their knowledge of commutativity and additive composition.

Furthermore, in keeping with previous research on the development of understanding of additive commutativity (Baroody & Gannon, 1984; Bermejo & Rodriguez, 1993; Canobi *et al.*, 1998, 2002, 2003; Cowan & Renton, 1996; Langford, 1981; Sophian *et al.*, 1995a), and additive composition concepts (Baroody *et al.*, 2003; Martins-Mourao & Cowan, 1998), the findings demonstrate that when conceptual tasks are structured in a way that provides a more explicit measure of analogical transfer between problems, young children frequently appear to use analogical relationships to solve addition problems. However, it is noteworthy that analogical reasoning was found to be more common for one type of conceptual relation (commutativity) than for the other (additive composition). These findings support the development trend in conceptual knowledge previously identified by Canobi *et al.*, (1998, 2002, 2003), Close and Murtagh, (1986) and Langford, (1981). Furthermore, children's ability to make analogies (based on the commutativity principle) was found to be independent of age (e.g., Canobi, 2004; Canobi *et al.*, 1998). However, on reflection this finding is not surprising given that analogies are considered to be an early developing skill (Goswami, 1992, 2001a) and that young children show an early appreciation for commutativity from around 4 to 5 years of age (Canobi *et al.*, 1998, 2002, 2003; Cowan and Renton, 1996; Sophian, Harley & Vong, 1997).

The findings also suggest that the children's experience of solving unrelated problems more generally also contributes to this use of analogical reasoning in addition. As expected, there were links between addition analogy skills and patterns of addition problem solving. In Study 3, children's success in using commutativity-type analogies in addition was related to advanced problem solving characterised by (a) the ability to retrieve answers from memory, (b) the use of decomposition procedures and (c) the frequent use of advanced counting procedures, such as counting-on from the largest

addend. The results from Study 3 indicated that, compared to their less advanced peers, children who showed high levels of using analogy to solve conceptually related addition problems tended to use more flexible and more sophisticated problem solving procedures when solving other types of addition problems. Although problem solving sophistication increased with children's age, the relationship between analogical reasoning and problem solving remained robust even when age related differences were accounted for (Canobi, 2004; Canobi *et al.*, 1998). The finding suggests that there is a systematic relationship between the ability to use knowledge of commutativity relations appropriately in order to solve conceptually related addition problems and the sophistication of children's procedural skills. This finding is important as this illustrates the types of gains that can be made by recognising shared underlying concepts between addition problems. However, the direction of this relationship between children's use of analogy and their problem solving sophistication requires further detailed investigation as it is not clear whether analogical reasoning skills actually lead to more sophisticated problem solving profiles.

9.1.3. The Contribution of Traditional Analogical Reasoning Skills

The third research question was concerned with whether children's ability to use analogies in reading and addition is related solely to their domain-related knowledge or whether this kind of reasoning is based on the development of analogical reasoning abilities more generally. As noted in Chapter 1, earlier theoretical explanations tended to assume that there are maturational domain-general shifts in analogical reasoning, suggesting that once children have mastered the general principles underlying analogical reasoning (e.g. by attempting to establish relational similarity) then they will be able to apply this reasoning strategy in any knowledge domain. According to this type of explanation, children become better at reasoning in all domains as they become older and more experienced (e.g. Piaget *et al.*, 1977). However, while there is little empirical

support for this position, it is important to acknowledge it, as it raises the possibility that children's ability to reason about relations in reading and addition may in fact simply reflect their ability to reason generally, rather than reflecting domain-specific skills. The relationship between reading and addition analogies and other forms of traditional reasoning skills was examined in Studies 2 and 3.

If the development of some sort of general analogical reasoning ability underpins children's ability to use analogy to solve reading and addition problems, then it was expected that children's scores on traditional analogical reasoning tasks would provide at least some explanation for the variability in children's efficiency in using analogies within the specific domains of reading and mathematics. However, as the results showed, this prediction was not fully supported by the data.

The results from Study 2 suggest that only some forms of general analogical reasoning ability, namely the ability to make visual analogies, predicts children's success in using both orthographic and phonological analogies in beginning reading. Visual reasoning skills were found to predict over 7% of the variance in orthographic analogy and 8% for their phonological analogy scores even when age and pre-existing domain knowledge were taken into account. This finding suggests that children's ability to notice visual similarity is related to their performance in making analogies in the domain of reading. This finding supports previous claims by Wood (1999) who reported similar effects in her research. Using stepwise regression analysis, Wood (1999) found that whilst phoneme awareness was able to account for 40% of the variance in children's orthographic analogy use, children's performance on the visual analogical reasoning task contributed an additional 5% to the overall variance. What is interesting is that this effect is only found for the visual reasoning task and not other forms of traditional reasoning skills (e.g., analogies based on thematic or causal relations). A closer examination of the

possible relationship between orthographic analogy and other forms of visual reasoning tasks would therefore be a useful extension to this work because it is still unclear whether different variations of visual analogical reasoning skills are related to analogical reasoning within specific educational contexts such as reading.

Furthermore, although the findings from Study 2 offer further support for Wood's findings, she did not compare children's visual analogical reasoning skills with their profiles of orthographic analogy skill in reading. This issue was addressed in the present research. Interestingly, Study 2 showed that when children's analogy scores were grouped according to the speed and accuracy across different trials, identifying four distinct groups, differences between these groups could not be explained by children's performance on traditional analogical reasoning tasks. This finding implies that children's efficiency in solving traditional analogical reasoning tasks does not explain individual differences in reading analogy. Therefore, although, as Wood (1999) suggests, visual reasoning skills are important predictors of orthographic analogies in early reading, this is not strong enough to discriminate between those children who are efficient in using orthographic analogies and those who are less efficient in using analogical reasoning skills in beginning reading.

In contrast, Study 3 examined children's performance on the traditional analogical reasoning tasks to see whether there was a relationship between this and their ability to use analogies in addition. The findings, unlike Study 2, show that there was no significant relationship between children's use of addition analogy and their performance on more traditional forms of analogical reasoning. Although age and understanding of number concepts provides some concurrent prediction of children's ability to use addition analogy, their ability to solve traditional analogical problems, namely, thematic, causal and visual reasoning skill, offered no explanation for their use of analogies in addition.

That is, analogical reasoning skills outside of the addition domain can contribute very little, if any, towards children's success in reasoning about relations in early addition. This finding supports previous claims that children's reasoning in addition depends closely on their knowledge of the domain concepts (e.g., Gelman, 1990; Gelman & Brenneman, 1994; Gelman & Gallistel, 1978; Gelman & Greeno, 1989), and that young children's ability to learn and reason arithmetically with natural numbers is guided by domain-specific principles and concepts within the addition domain and not by their general analogical reasoning skills (Gelman, 2000; Gelman & Gallistel, 1978). This would imply that reasoning skills, once embedded within the specific domain of addition, are not bound by domain general principles but instead they are constrained solely by children's domain knowledge and expertise within that particular domain. However, it is important to note that after controlling for the effects of age and pre-existing domain knowledge, the next best predictor of using analogies in addition was their visual analogical reasoning scores and this suggests that perhaps some form of visual reasoning ability may still be important for analogical reasoning skills in addition.

These findings also have important theoretical and educational implications for teaching young children the domain principles underlying the reading and mathematics domain. Although children's ability to reason about relations in reading may reflect a more general ability to reason analogically, this does not appear to be the case for addition. Instead, the findings imply that once analogical reasoning skills are embedded within specific domains, such as addition, they are constrained solely by appropriate domain knowledge and not by the child's proficiency in using analogies generally. Educationally, this finding is important because it implies that teaching children generic analogical reasoning skills divorced from the context of teaching them about more specific addition skills will have very little impact on their mathematical understanding

and educational development. It should be noted, however, this finding might only apply to the traditional forms analogical reasoning tasks (causal, thematic and visual reasoning tasks) employed in the current research program and may not apply to teaching children to look for relational similarities more generally.

9.1.4. Consistency in Children's Strategy Choices

The fourth research question was concerned with whether there is any consistency in children's use of analogies within early reading and addition or whether children report using different strategies for solving analogical problems within these two task contexts. The findings from the present studies strongly endorse the usefulness of adopting more precise research methodologies, such as self-reports, as indices of children's performance in reading and addition. In Study 4, individual strategy choices in reading and addition were examined, and the speed and accuracy associated with each of these different strategies was compared. Although children were presented with different types of reading and addition problems in Study 4, only those strategies used to solve related analogy problems were examined as the main research question here addressed whether children were consistently applying their knowledge of relations to solve such problems. Using self-reports of strategies, the findings suggest that young children are not consistent in the use of analogy in reading or addition. Instead children often report to be using a wide repertoire of strategies to solve the related analogy problems in both task contexts. For example, in the reading task, children reported using a variety of different strategies to solve the conceptually related reading problems including guessing, analogy, sounding-out and a combination of the both analogy and sounding-out. The speed and accuracy associated with each of these different strategies also varied according to the strategy used by each child. This finding is particularly striking because unlike previous studies that have suggested that all children use a common strategy when first beginning to read (see

Goswami, 1992, 1993), children's analogical performance is not consistent across trials or across problems. Although children may report using analogies to solve related problems on one occasion, they do not report using this strategy consistently across all related problems in the Reading Analogy Task. This finding is also important because current theoretical models of reading development do not take variability in children's strategy choices into account completely (e.g., Goswami, 1993, 1999a; Goswami & Bryant, 1990). Given the results of Study 4, however, it would appear that the existing theoretical accounts of early reading development need to be developed further in order to fully account for variability in children's strategy choices in reading.

Study 4 also demonstrated that children were reporting using a wide repertoire of strategies to solve addition problems (Baroody & Gannon, 1984; Baroody *et al.*, 1983; Carpenter & Moser, 1982, 1984; Geary & Brown, 1991; Geary *et al.*, 1991; Goldman *et al.*, 1989; Siegler, 1987, 1989). As was found for the Reading Analogy Task, children did not consistently apply an analogy strategy to solve conceptually related problems. Success on these conceptually related problems was accompanied by self-reports where children claimed to be using a combination of alternative strategies including retrieval, decomposition, making analogies and counting procedures. While children do not apply an analogy-based strategy consistently to solve all possible related addition problems, on the occasions when they do apply such a strategy, it appears to be quicker and more accurate compared to other strategies. The finding that young children have the proclivity to use many different strategies to solve the same type of addition problem is important as it suggests that children need to develop an understanding of which type of strategy is most suited to a particular type of problem. It is clear, however, that it is only by studying how children's reported strategy choice changes from problem to problem within the context of a single task that a detailed and accurate characterisation of the progress of

their mathematical understanding will be achieved. The findings from Study 4, therefore, offer strong support for Siegler's (1988a, 1996) claims that children do not always use the most advanced or apparent strategy that is available to them in any one task and that more detailed microgenetic methods for studying children's development is needed.

The findings from the present studies demonstrate that simply comparing average performance measures between age groups and neglecting to interrogate children's own self-reported strategy use (e.g., Goswami, 1986, 1988, 1990a, 1990b, 1993; Goswami & Mead, 1992; Muter *et al.*, 1994; Wood, 1999, 2000, 2002), are not likely to provide a satisfactory account of the development of children's early reading and mathematical understanding. Furthermore, it is reasonable to suppose that this argument would also apply to investigations of children's performance in other areas of cognition. The findings indicate that attempting to study analogical reasoning skills without the use of appropriate verbal report measures, may lead to an incomplete understanding of children's knowledge. In contrast, examining the speed and accuracy of individual strategies is likely to lead to an important contribution helping to clarify the extent to which children are consistent in their use of various reasoning skills and thus, promote alternative theoretical accounts of development (Siegler, 1996).

9.1.5. Patterns of Analogy across Domains

Finally, the fifth research question was concerned with establishing whether there are any similarities in children's approach to solving analogical problems when their performance on the Reading Analogy Task was compared with their performance on the Addition Analogy Task. This is an important question because if there is evidence of cross-domain consistencies in children's analogical reasoning in reading and addition then this finding could inform educational practice regarding how best to teach children to recognise, appreciate and apply their understanding of relational similarities between

problems which may be a useful strategy that can be applied in many different educational contexts (see also Siegler, 1988). If there is some suggestion that children use the same kinds of analogical skills in the context of solving of both reading and addition problems then, this would have theoretical implications for current cognitive developmental models of analogical reasoning (c.f., Piaget *et al.*, 1977; Goswami, 1992, 1996).

Study 4 examined this possibility by comparing the performance of the same group of children on both the reading analogy and the addition analogy task. Comparisons across the different trials in each of these tasks were systematically carried out. Stepwise regression analysis implied that there was some evidence of a cross-domain analogical component to children's reasoning on the two tasks. Children's efficiency in solving analogies in reading could be predicted by their reasoning scores in addition. This effect remained robust even when the ordering was reversed. Reading analogy scores were also found to concurrently predict the use of analogies on the addition task. This finding, however, does not necessarily imply that analogical reasoning skills are completely domain general. Instead the type of interaction, found in Study 4, may simply illustrate how children's analogical reasoning in one specific domain is similar to their analogical reasoning in another specific domain when prompted to use analogical relationships. The results may, however, indicate a strong shared analogical component when looking at the two domains concurrently. Although this effect was illustrated in Study 2 by identifying links between reading analogy and other visual forms of analogical reasoning skills, this was something that was not illustrated in Study 3 when using traditional reasoning tasks (based on general forms of causal, thematic and visual relations).

In addition to the regression analysis, distinct patterns of reasoning skills were identified based on the strategies that children reported using to solve the related

problems in the reading and addition analogy tasks. The majority of children showed a strong similar ability to use analogies in both reading and addition. Base line measures of single word reading and understanding of number concepts indicated that these children were less advanced in terms of their early reading development and mathematical understanding than other children. The results showed that the less efficient children were younger and that if they used analogy it did not necessarily help them arrive at the right answer, and/or they did not appear to have any useful strategies. Slightly older children who showed a more developed understanding of either reading or early number concepts than the majority of children, tended to use alternative, yet equally successful knowledge-based strategies. These children demonstrated a tendency to use analogical reasoning strategies in either the addition or the reading tasks but not both. For these children, the availability of alternative, knowledge-based strategies appeared to be related to superior performance on baseline measures of single word reading and number concept understanding. In contrast, the youngest children, or those that performed below average on the baseline measures were also those who, although reporting to use analogy, had lower accuracy scores on the analogy related problems and were also those who did not appear to have recourse to any other appropriate strategies. In the context of the tasks used in the present studies, these findings would suggest that while analogies are an important reasoning strategy that is used with increasing efficiency, this strategy begins to be replaced by other strategies that demonstrate children's developing understanding of domain-specific principles and procedures.

Nonetheless, overall there was evidence of some domain general analogical component underlying children's performance in both domains. The present findings demonstrate that the children's ability to reason about relations in one specific domain, (e.g., reading), is similar to their ability to reason about relations in another highly

specific domain, (e.g., addition). The results imply that children's ways of thinking about relations across reading and addition is strikingly similar. That is, their ways of thinking about relations in words and ways of thinking about relations in number concepts are equivalent for many young children. It is important to note that the present results, however, tell us very little about the nature of this shared analogical component. It is possible that the current findings do represent some aspect of domain general thinking because Study 2 illustrates that the ability to use analogies in reading (although not in addition) are related to traditional analogical reasoning skills generally. Although there is some suggestion of cross-domain skills it is likely that the explanation for this shared variance does not appear to reside in the traditional forms of analogical reasoning. Given high levels of similarity in children's reasoning skills in reading and addition, it is recommended that further empirical research is needed to explore this shared analogical component to examine whether this reflects an underlying domain general analogical component across different educational contexts.

9.2. Implications of the Present Findings

The purpose of this section is to summarise the main contributions of the present research and to identify the ways in which the research has addressed relevant theoretical, methodological and educational issues.

9.2.1. Theoretical Implications

The various studies reported in this thesis have demonstrated the usefulness of identifying differences in the way in which children of the same age respond to orthographic and phonological relations by examining patterns of performance across different trials of the Reading Analogy Task. As has been previously pointed out, existing research on reasoning skills in reading has neglected to identify these differences due to a

tendency to focus on averaging data across individual children (see Goswami, 1986, 1988, 1990a, 1990b, 1993; Goswami & Mead, 1992; Wood, 1999, 2000, 2002; Wood & Farrington-Flint, 2002). However, as illustrated in Studies 1, 2 and 4, a more detailed understanding of children's analogical performance can be provided when research considers variation among children of the same age and considers possible alternative pathways to reading success. The results from Studies 1 and 2 in particular suggest that restricting research to looking at children's performance across age groups or across individuals can limit the kind of theoretical claims that can be tested (Siegler, 1996). Indeed, such research may lead to inaccurate conclusions by under-emphasising variation in children's knowledge.

Studying patterns of children's responses on different orthographic and phonological indices also contributes to our current understanding of the debate surrounding phonological priming. This debate concerns whether children rely solely on the pronunciation of the clue word in the Reading Analogy Task as a basis for making an orthographic analogy or whether they use other possible strategies (Bowey, 1999; Bowey *et al.*, 1998; Goswami, 1999c; Nation *et al.*, 2001; Roberts & McDougall, 2003; Savage, 2001, 1998). However, as shown in Studies 1 and 2, it is likely that this debate can be resolved by acknowledging that while some children use a phonological strategy almost exclusively, other children use this strategy in combination with alternative strategies or may not use a phonological strategy at all when attempting to read unfamiliar words. Studies 1 and 2 both revealed that while orthographic analogies based on phonological relations are an important aspect of children's reading development they were not used exclusively or consistently by the children participating in these studies. The cluster analyses revealed the existence of subgroups of children each of which showed a different pattern of performance on the Reading Analogy Task. While some children could read

target words in both the orthographic and the phonological analogy conditions other children were only successful in the orthographic analogy condition and some children did not manage to read the target words in either condition. This suggests that, contrary to some earlier claims (see Ehri, 1998; Frith, 1985; Goswami, 1993; Marsh, Desberg, & Cooper, 1977; Marsh, Friedman, Welch, & Desberg, 1981), there is no single pathway that can be said to characterise children's early reading development. This is an important finding. It has implications for the ways in which children are taught to read and suggests that reading instruction programmes that concentrate on teaching all children in the same way, (e.g. exclusively phonologically-based programmes) may not meet the developmental needs of all children.

Studies 3 and 4 have also illustrated the salience of analogical reasoning skills with regard to the development of children's acquisition of addition principles. Exploring the role of analogy in the domain of early mathematical understanding is important, as this has not been systematically explored in an explicit way. As argued in Chapter 3, traditionally there has been no attempt to tie the analogical reasoning literature to the literature on the development of children's understanding of addition. This is problematic because analogical reasoning may play an important role in the way that children learn about addition principles. The present research has shown that a more detailed account of analogy use in the context of the addition tasks used in Studies 3 and 4 can contribute to the development of a more detailed theoretical account of how children begin to acquire knowledge of addition principles. The present findings suggest that a developmental domain-specific account of analogical reasoning in early addition is beginning to emerge. Children's performance on the Addition Analogy Tasks used in Studies 3 and 4 suggest that initially children are able to use an analogical reasoning strategy to perceive relational similarities between commutativity problems and that only later do they begin

to apply this strategy to additive composition problems (e.g. Canobi *et al.*, 1998, 2002, 2003; Close & Murtagh, 1986; Langford, 1981).

Another theoretical contribution of the present research has been to demonstrate how the use of verbal self-reports are particularly important in order to identify the accuracy of children's early analogy performance and to test theoretical claims regarding the validity of analogy in early reading (rather than simply exploring accuracy data). Self-reports can help to verify whether or not children are actually using an analogical reasoning strategy in reading. This is important because without verbal self-report data we have no way of really telling, apart from by inference, that children are actually using relational similarity in the analogy conditions to read the target words or to solve the target addition problems. The findings from Study 4 demonstrate that young children report considerable variability in the types of strategies they use in the context of the reading and addition tasks employed here. Again, this highlights the dangers of basing interpretations of children's performance on analyses that average performance scores both across individuals and across strategies. The use of self-reports can, therefore, inform the existing developmental literature about the importance of acknowledging variability in children's strategy choices and this may have implications for the way in which we study children's cognitive development across a variety of different domains or contexts (see also Siegler, 1996). It is likely that previous researchers have not attempted to elicit self-report data previously because they think that young children do not have sufficient verbal skills or self-reflective awareness to explain and articulate their own reasoning or thought processes. However, in the present research, it has been demonstrated otherwise and this is an important contribution.

Exploring the nature of analogical reasoning and its development across different educational domains as was achieved in Studies 2 and 3 also contributes to the way

children's analogical reasoning skills are characterised within the developmental literature. In Studies 2 and 3, a direct comparison of children's performance on traditional forms of analogical reasoning tasks (based on causal, thematic and visual relations) were conducted to explore whether these scores can successfully predict young children's use of analogies on reading and addition tasks. The findings show that whilst there is some support for the claims that traditional forms of analogical reasoning, in particular visual reasoning ability, may be associated to the use of analogies in beginning reading (see Wood, 1999), there was no support for this claim in the context of addition. In Study 4, however, there was strong evidence to suggest that children approach specific analogy-based problems in reading and addition in a very similar fashion. There is, therefore, evidence for some shared variance in analogical reasoning skills across the two domains of reading and addition although this is only weakly related to their performance on traditional analogy tasks. As noted already, this suggests that the explanation for this cross-domain analogical skill does not necessarily reside in accounts of the development of traditional forms of analogical reasoning.

However, there might be alternative explanations that could account for the pattern of performance on the addition and reading tasks. One possibility relates to the 'demand characteristics' of these two experimental tasks. In both the reading and addition analogy tasks children were provided with very specific clues as to the sort of information that would help them solve the problems, a) they were told that the clue word/or sum might help them solve the target word/addition sum; b) the clue word/sum remained in view. Therefore, only a minority of children should fail in their attempts to try to establish some sort of correspondence between clue and target and notice visual relational similarities where these existed. In other words, it could be argued that the current tasks primed children to use an analogical reasoning strategy based on relational similarity. This might

not be the strategy they would naturally use at this age (indeed the self-report data shows that they have a variety of strategies available to them and that they did not always use the most obvious or primed strategy). However, what the present research has shown is that children between 5 to 7 years of age can use analogy-based strategies when primed to do so, but that they do not do so universally, even when primed. Furthermore, if they are not using analogical reasoning all of the time then it is not surprising that performance on traditional analogy tasks is a poor predictor of performance on items that can be solved by analogy. Nevertheless, it is clear, as shown in each of the experimental studies presented in this thesis, that many 5 to 6 year-old children are capable of noticing relational similarity where this exists, and that they can use this to read unfamiliar words (even though these are pronounceable non-words with no real meaning) and also to solve mathematically related addition problems.

More importantly, the findings presented in the thesis can also contribute to developing a new, and refined theoretical account of analogical reasoning, one that considers analogical performance across different educational domains. Although, as noted in Chapter 1, there are current theoretical models of analogical reasoning, these accounts are often based on incorrect assumptions regarding children's analogical abilities (see Goswami, 1992). For example, Piaget's theoretical account suggests that children cannot use analogical reasoning skills until the stage of formal operational thought, which begins to develop around 11 years of age. Piaget's approach reflects maturational shifts in children's analogical reasoning, suggesting that children become 'domain-general' reasoners as they become older and more experienced. However, there has been no research that examines whether there is a domain general analogical component that might underlie young children's reasoning abilities across different knowledge domains. In contrast, Goswami's knowledge-based view of analogical

reasoning assumes that the relational shift results from changes in knowledge, and not from global and/or maturational changes in development (see also Brown, 1989, 1990; Brown & Kane, 1988; Chen & Daehler, 1989, 1992; Crisafi & Brown, 1986; Goswami, 1992; Vosniadou, 1989, 1995). According to this view, children should be able to use analogical reasoning skills from very early in their development and this should be apparent within different educational contexts. However, despite claims regarding the salience of analogy in early development, no experimental support has been offered for these theoretical accounts that has specifically compared children's analogical reasoning skills across different educational contexts. The evidence presented here suggests that there appear to be individual differences in reasoning skills with the samples of 5 to 6 year-old children who participated in the various studies. This provides a more detailed insight into analogical reasoning skills across different domains. Furthermore, the approach taken here can potentially offer a more refined theoretical account of the role of analogical reasoning in children's cognitive development.

The present research suggests, nonetheless, that whilst analogical reasoning skills are important early in children's development in the reading and addition domain, the ability to use analogical reasoning skills may not necessarily be a developmentally sophisticated skill. In Study 1, patterns of responses on using orthographic and phonological relations in reading were identified using cluster analysis. These patterns show that only one group of children were genuinely using relations based on shared visual similarities between words. This group of children, however, had the lowest levels of pre-existing domain knowledge. In contrast, it seems that using a phonological approach to reading (rather than an orthographic based visual approach) is related to apparent increases in their domain knowledge. A reasonable interpretation might be, therefore, that the genuine use of orthographic analogies in reading occurs very early in development prior to any

understanding of appropriate domain knowledge. In line with this, Study 2 also shows that the children who appeared to use more genuine forms of orthographic analogies were those who had lower scores on standardised measures of phonological awareness. Taken together, these findings suggest that the ability to make orthographic analogies may be an early developmental strategy used by children who have yet to develop more sophisticated, domain specific knowledge such as an understanding of particular kinds of knowledge used in reading.

The findings from Study 4 strengthen this particular interpretation. In this study, which included self-reports of strategies, the children with the lowest scores on measures of domain knowledge (single word reading and number concepts) were those who used analogical reasoning strategies in the context of both the reading and addition tasks. Children with higher levels of domain knowledge, however, demonstrated a tendency to use analogical reasoning in either one domain or the other but not in both domains together. These children also reported using alternative strategies to solve the related problems in either addition or reading. This suggests that with increases in domain knowledge, and problem solving experience, children begin to discover alternative (and perhaps more sophisticated) strategies in reading and addition and this is reflected in their performance. Further work will be needed to substantiate this interpretation.

9.2.2. Methodological Implications

There are also important methodological implications of the present research that need to be addressed. In relation to the domain of reading, a strong methodological contribution was examining the reliability of the Reading Analogy Task and assessing the most useful way of exploring analogical reasoning in the reading domain. Direct comparisons between real word and non-word tasks in Study 1 revealed that the inclusion of non-word test items may provide a better assessment of analogical performance,

without the possible confounds of word frequency (see Wood, 2002; Wood & Farrington-Flint, 2002). Very often the effects of high word frequency may have serious implications for the type of conclusions the research can draw from the clue word studies (see Wood, 2002). According to the claims made by Wood, the scores on the rhyme-based items may be artificially inflated by the use of high frequency words and this, coupled with an apparent tendency in children to generate rhyme based guesses, would result in a number of false positives. To verify Goswami's claims regarding the importance of orthographic analogies in reading, her findings needed to be replicated using a task that control for the effects associated with high word frequency. In the present research it was shown that redefining the clue word task as a measure of analogy in reading incorporating non-word items can offer a stringent account of children's use of analogies in reading. There was strong internal consistency for the non-word measure and the children's scores on this task were replicated in Studies 2 and 4 showing equivalent levels of performance. It is argued that these findings provide further support to using a non-word Reading Analogy Task as an appropriate measure of orthographic analogy skills in future research.

A further methodological contribution was designing a useful measure of analogical reasoning in relation to children's simple addition. Traditional conceptual tasks have tended to ignore analogical reasoning skills. Some conceptual tasks (Baroody, 1987a; Baroody *et al.*, 1983; Canobi *et al.*, 1998, 2003; Putnam *et al.*, 1990) have been concerned with measuring children's ability to judge and explain problem relations rather than examining whether they can solve related problems by analogy. In other conceptual tasks, children are required to spontaneously notice problem relations between related pairs interspersed with randomly ordered problems (e.g., Canobi, 2004; Canobi *et al.*, 1998, 2003). However, the advantages of designing and implementing new methodologies for studying analogical reasoning in addition have been illustrated in

Study 3. There was evidence of children's ability to use analogical reasoning using an Addition Analogy Task. Also high internal reliability was found suggesting that this task may provide an accurate and sensitive measure of analogical reasoning in this domain. It is suggested, therefore, that this analogical reasoning task can provide a good methodological framework for examining analogical reasoning in the context of mathematics in the future.

Finally, as discussed previously, another important benefit of the present research is exploring the usefulness of children's individual self-reports and providing explicit measures of individual strategy choices. Although self-reports are frequently used in the context of addition (Canobi *et al.*, 1998, 2002, 2003; Siegler, 1987, 1989), there has not been, until fairly recently, any explicit attempts at measuring the types of strategies that children use when solving analogical problems in the context of word reading. It was argued in Chapter 2 that previous research concerned with studying children's use of orthographic analogy in reading is weakened by difficulties in using inappropriate measures for examining individual strategy choices. An important methodological contribution of the present research has therefore been to illustrate the potential benefits of analysing children's individual strategy choices and how such assessments can lead to more informed judgements regarding cognitive models of reading development.

9.2.3. Educational and Practical Implications

The findings from the present research have strong educational and pedagogical implications. One possibility that is raised in the current research is that teaching young children to use analogies of concepts in reading and addition might play an important role in their development of knowledge and problem solving sophistication within these particular domains.

In Studies 1 and 2, the findings show that young children are able to make analogies as a strategy for reading unfamiliar words. Given that children are able to explicitly use their knowledge of spelling-sound units such as rime and phonemes to make analogies in reading, the results suggest that when taught explicitly in schools, analogies may provide young children with an important strategy in the initial stages of learning to read (Goswami, 1993, 1994, 1995a, 1999a). Moreover, characterising children's skills in terms of patterns of performance across orthographic and phonological indices can help explain why some children are struggling in their early reading development whilst others are successful readers. For example, in Study 2, it was found that children's reading proficiency, and phonological awareness (but not vocabulary or short-term memory) were concurrent predictors of reading analogy in 5 to 6 year-old beginning readers. According to the findings, each of these domain appropriate skills were able to provide a good significant contribution to reading analogy and furthermore that such skills, in particular phonological knowledge, could explain the distinct patterns of reasoning identified in the cluster analysis (see also Goswami, 1995a, 1999a). By comparison, Study 2 found that there was very little association between traditional analogical reasoning skills and these profiles of reading by analogy. Given that traditional analogical reasoning skills cannot discriminate between the different profiles, it is possible that children in each of the different profiles all have similar levels of traditional analogical reasoning ability. That is, those children who were less efficient in using orthographic analogies in reading were not necessarily poor in solving traditional analogical reasoning tasks when compared to the more efficient reasoners. The relations between traditional analogical reasoning and reading analogy may address important educational concerns that teaching children traditional analogical reasoning skills may be beneficial to their development in specific domains like reading, although this requires more detailed examination.

In Study 3, the salience of analogy to children's addition knowledge was examined. In keeping with previous research indicating that many young children understand additive commutativity (Baroody & Gannon, 1984; Bermejo & Rodriguez, 1993; Canobi *et al.*, 1998, 2002, 2003; Cowan & Renton, 1996; Langford, 1981), and additive composition (Martins-Mourao & Cowan, 1998), the research has shown that young children are able to use these principles as a basis for making analogies within addition.

It may be the case that some of the children in this study would benefit from direct instruction that makes explicit the implications of analogical relations between problems for problem solving. This is likely given that many 5 year-olds in the study were able to make analogies based on commutativity-relations. When children did solve conceptually related problems using other types of mathematical knowledge such as commutativity, they achieved fast and accurate performance. An educational emphasis on using addition principles to complement problem solving skills might strengthen these skills so that as children gain experience in solving problems they will also learn about the benefits of making analogies between conceptually related problems in addition (see Canobi, 2004). Furthermore, the finding that traditional analogical reasoning skills did not contribute to domain-specific forms of analogy within addition suggests that children's knowledge of the domain, and not some more general capacity to look for and reason about relations, is a stronger prerequisite for the use of analogy in addition. The finding that performance on the addition analogy problems was not predicted by performance on traditional analogical reasoning tasks again implies that teaching children generic reasoning skills is not likely to help the development of domain-specific problem solving procedures such as those used in addition. Instead, teaching children directly about principles such as commutativity, associativity and additive composition may lead to a more refined use of

analogical reasoning to solve addition problems. Although, again, this possibility requires further consideration in future research.

In Study 4, possible links or commonalities in the way children approach analogy problems in both reading and addition together were systematically examined. Finding strong links between children's reported use of analogies in both reading and addition suggests that there may be an important role for teaching children to use appropriate analogical reasoning strategies in other educational domains. However, it may be of benefit to educational theory and practice to explore the types of gains that can be made by explicitly teaching analogical reasoning skills in reading and addition and whether such skills complement children's understanding of principles across the two domains directly. Therefore, a possible goal for future research may be to explore whether young children, after being taught analogical reasoning skills in one specific domain (e.g., reading), can then spontaneously transfer this knowledge across to other specific educational domains (e.g., addition). These suggestions for future research will be discussed in more detail in the following section.

9.3. Directions for Future Research

This section considers directions for future research and provides some suggestions concerning how the present findings can be developed further. There are three main areas in which further studies based on the research reported in this thesis that can be carried out. These will be discussed in detail next.

9.3.1. Individual Differences in Beginning Reading

One of the central aims of the research was to examine the possibility of identifying meaningful patterns of individual differences in children's use of orthographic and phonological analogies in reading. There were also attempts to try and explain these

different patterns of analogy in children's reading. For instance, one hypothesis already examined within this thesis is that children's pre-existing domain knowledge, phonological awareness and their traditional analogical reasoning skills could provide some explanation for the distinct patterns of analogy in beginning reading. However, it could be argued that an important limitation of the present research was its limited focus on using only a few measures phonological awareness and reading skills as predictors of reading analogy. Attempting to examine the extent to which other reading related skills could explain individual differences in reading analogy can extend these findings even further.

It is important to examine the extent to which different measures can help to explain these patterns of reading analogy in young children. In the thesis some consideration of how children's pre-existing domain knowledge skills, such as single word reading, receptive vocabulary and phonological awareness can predict analogical reasoning in early reading. The findings support previous experimental findings that phonological awareness and single word reading are important to children's analogical reasoning skills in reading (Goswami, 1990b; Goswami & Mead, 1992; Muter *et al.*, 1994; Roberts & McDougall, 2003; Walton, 1995; Walton & Walton, 2002; Wood, 1999, 2000, 2002; Wood & Farrington-Flint, 2002). It could be argued, however, that other reading-related skills need to be examined. Perhaps a useful way of extending the present findings is to assess the contribution of letter-sound knowledge and different variations in phonological tasks (e.g., rhyme and phoneme skills measured on production, segmentation and deletion tasks). Although domain knowledge appears to be the most important predictor of individual differences in reading, not all measures of domain knowledge will offer the same contribution so it is necessary to identify which offer the best explanation overall.

Another way of extending the present findings is to examine children's analogical performance over longer periods of time and to consider how these profiles of reasoning change over time. This was a limitation with the present research that needs to be considered further. In the present research, phonological awareness was found to be a strong predictor of reading analogy profiles, when examined cross-sectionally. However, whether this finding remains consistent over time remains unknown. Indeed, it could be argued that a more appropriate examination of the possible causes of individual differences in reading by analogy would be a longitudinal one. In the present research, distinct patterns of orthographic and phonological relations were found within the context of reading, however, these findings only relate to beginning readers between 5 to 6 years. Whilst phonological skills and reading proficiency at 5 years were found to be strong predictors of individual differences in reading by analogy, there is no guarantee that the same skills remain the most robust predictors of analogy over time. Therefore, it is important to establish whether those predictors of analogy profiles at time 1, specifically phonological skills, also continue to be strong predictors of analogy profiles at time 2. This form of investigation would establish whether the same predictors of reading analogy profiles at 5-years continues to remain strong and significant predictors of patterns of analogy a year later, when the same children become older, and more experienced with reading. This type of study would be informative in developing current cognitive models of reading.

Finally, as already noted, the contribution of traditional analogical reasoning skills to these patterns of reading is less clear. Although children's ability to make visual analogies can contribute to their orthographic analogy in the context of reading when measured using regression analysis, there was no differences between groups of children using a cluster analytic technique. This finding suggests that efficiency in using traditional

analogical reasoning skills cannot contribute to variation in using analogies in the reading domain. However, this possibility of finding links between visual forms of analogical reasoning and orthographic analogies in reading needs to be addressed further to rule out this possibility completely. One way of addressing this issue is to devise a series of more visual forms of analogical reasoning skills and to make further comparisons between patterns of reading and these visual analogical reasoning measures. It is likely that this specific relationship between traditional analogical reasoning skills and reading analogy is specific to visual reasoning skills because there was no effect found for children's scores on the thematic reasoning or causal reasoning tasks. Therefore, a closer investigation to the role of visual analogical reasoning skills in early reading is justified. It is suggested that a more detailed examination of the possible relations between visual reasoning skills and orthographic analogies is needed. A recommendation for future research is to devise a series of alternative visual reasoning tasks that were not included in the present study. This form of investigation would help to clarify whether a broader range of visual analogical reasoning measures could explain the patterns of analogy identified in the present research.

9.3.2. Analogical Reasoning across Educational Domains

Another area that requires further research is the possibility that there may be strong systematic links in children's analogical reasoning performance across a variety of different educational domains. In the present research, Study 4 found high levels of consistency in children's use of analogy in both reading and addition when examined together. However, focussing solely on possible comparisons between children's reading and addition limits the kinds of conclusions that can be made regarding the importance of analogical reasoning.

The finding from Study 4 suggests strong similarities in children's use of analogies across the two domains of reading and addition. However, at the same time the current findings do not necessarily indicate that there is a strong a 'domain-general' analogical component underlying children's performance in these two domains. Instead, the findings illustrate possible similarities in the way 5 to 6 year-old children approach the task of solving problems in the contexts of reading and addition. It is likely that analogical reasoning skills may be domain general because in Studies 2 and 3, there was some indication of a relationship between traditional forms of analogical reasoning skills (visual skills) and domain-specific forms of relational reasoning (in reading and addition, specifically). However, this issue needs further examination. It may be possible to examine this relationship more thoroughly by examining children's use of analogy across a series of different educational contexts, other than those included in the present research program.

With regard to the reading domain, a closer examination of the ways in which children explicitly use analogies in both reading and spelling would be a particularly useful way to characterise their analogical development and to address the domain generality of analogical reasoning. There is however, at present, no consideration of individual differences in children's spelling development and no examination of the possible strategies that children use to aid their spelling activities. Instead, similar to the reading domain, researchers have tended to use group averaged performance measures (e.g., accuracy) to make claims about children's strategy use in spelling without measuring strategies independently (although see Rittle Johnson & Siegler, 1999). There is a need, therefore, to look at the possibility of individual differences in children's strategy choices in spelling as this leads to the possibility of acknowledging different pathways to development. As shown in the current research, developing more sensitive

measures of children's strategy choice has important advantages in providing information on individual processes that is not available from performance scores (like accuracy) and providing the basis for a more stringent test of competence than achieved in previous research. It is proposed, therefore, that looking for distinct profiles in children's analogical reasoning skills across the two domains of reading and spelling together will be worthwhile.

It is often claimed in the developmental literature that children's use of analogy in reading and spelling progress through different stages of development which may be characterised by different skills at different ages (Frith, 1985; Nation & Hulme, 1994, 1996). However, as noted previously, theoretical models of development that concentrate on the identification of a single pathway to reading development may be limited because children may develop their own routes to reading. The same argument can be made about children's spelling. The potential benefits of exploring relations between analogies in reading and spelling together is underscored by claims that analogies are important for children's development in both reading and spelling and these may complement each other as children progress in learning to read and spell (see Goswami & Bryant, 1990). Therefore, looking for patterns of individual differences in children's analogical reasoning skills across these two contexts may provide a more detailed focus for extending current cognitive models of reading and spelling development.

With regard to the mathematics domain, a good way to examine the use of analogical reasoning in more detail would be to explore children's analogical reasoning in both addition and subtraction using tasks that require children to reason about relations within these two different contexts. In line with claims that addition is only understood fully unless it is understood in relation to subtraction (Bryant, Christie, & Rendu, 1999; Piaget, 1952), looking at how the same children approach the task of solving addition and

subtraction problems together would be beneficial. There has already been some investigation of the possible relations between children's understanding of concepts in addition and subtraction (see Bryant, Christie, & Rendu, 1999; Canobi, 2004), however, there is no current research that considers possible relations between the two contexts in terms of children's ability to make analogies based on concepts in addition and subtraction. Comparing children's ability to reason analogically in these two areas of mathematical development will further address the possibility of finding shared variance in children's analogical reasoning abilities across different educational contexts and may, in turn, provide a basis for extending current theoretical models of mathematical development (Gelman & Gallistel, 1978; Piaget, 1952; Resnick, 1983). Such an investigation will also be of benefit to educational theory and practice by illustrating the types of gains that can be made by explicitly teaching analogical reasoning skills in addition and subtraction and whether such skills complement children's understanding of addition and subtraction principles.

9.3.3. Educational Implications of Analogy Teaching

One of the original aims of this research was to examine similarities in children's analogical reasoning within and across different educational contexts. Now that this has been examined, the next phase of research can go on to determine the educational implications of teaching young children to recognise and incorporate analogical reasoning strategies into their learning. This may be important for reading, addition, and also have wider implications of promoting the use of analogical reasoning strategies for teaching and learning in more general ways.

One possibility for future research is to examine the development of children's analogical performance more fully. The present research has shown that for young children, around the ages of 5 to 6 years, analogies are particularly useful to their

development and understanding in both reading and addition. However, these findings only relate to children's performance at one specific point in time. There was no consideration of the longitudinal implications of these findings. It is likely that the types of strategies children use, and the extent to which they rely on using analogies in either reading or addition may change over time and this needs to be considered further. It would be interesting to see how with age and experience, children's reasoning abilities develop. Longitudinal studies charting children's development in their use of analogies within reading and addition are likely to lead to the identification of alternative pathways to acquiring domain knowledge. This could provide a wealth of potentially important information regarding how analogical reasoning skills develop over time, over trials and over different contexts (see Siegler, 1996).

Similarly, although the present research has illustrated strong commonalities in children's use of analogical reasoning in reading and addition, it did not address the spontaneous use of analogies in the classroom setting. Some of the educational implications of the findings have been raised in this thesis but there is a need for additional research to examine these suggestions experimentally. It is important to examine whether young children can naturally and spontaneously use analogies across these different educational domains through the use of intervention designs and longitudinal studies. For example, it is possible to examine the facilitative effect of teaching children to recognise and incorporate analogical reasoning strategies into their repertoire of skills through intervention studies. As noted already in Chapter 2, a particular advantage of identifying sub groups or profiles is the possibility of considering different variations in children's reading abilities and examining possible intervention programs more effectively. Lyon and colleagues (Lyon, 1983; Lyon *et al.*, 1982; Lyon & Watson, 1981), after identifying distinct profiles of reading difficulties, examined the

possible benefits of using a well sequenced synthetic phonics program to improve these children's reading abilities. While the use of cluster analytic techniques prove to be useful in evaluating alternative forms of reading-based interventions in dyslexia, a similar approach can be used to assess the effectiveness of phonics based reading programs with typically developing children. It is possible, after identifying different profiles of using orthographic and phonological relations in reading, to assess whether those children who are particularly weak in recognising analogies in both reading and addition, will benefit from explicit teaching. In such a design, 5 children can be taken from each of the corresponding clusters and matched on their single word reading, mathematical knowledge and their age. Systematic comparisons of their improvements in reading and addition after a short-term longitudinal intervention program can then be assessed to see which approach is most beneficial to children's development in the domain of early reading and mathematics.

Finally, it is also important to examine the possible gains in teaching children analogical reasoning skills across different educational contexts. A design such as this would examine the facilitative effect of teaching children to recognise and incorporate analogical reasoning strategies into their repertoire of skills through training studies. In order to truly test the shared analogical component fully, it is important to assess whether children's ability to use analogy strategies within one educational context, such as reading, can also be used across other domains when unprompted. That is, whether once taught to use analogies in reading, are young children able to transfer this knowledge across other specific educational domains, such as addition. It is necessary to consider the extent to which the use of analogies in one specific domain can facilitate reasoning in other specific domains in the absence of direct teaching. It is possible to design an empirical study whereby half the sample of children are given the Reading Analogy Task

and are explicitly prompted to use analogies in this task (but not in the Addition Analogy Task). The remaining half of the sample could then be taught to explicitly use analogies in the Addition Analogy Task (but not in the reading task). If children are able to use their knowledge of analogy in reading or addition and able to spontaneously use this strategy across other domains when not taught to do so, this finding would demonstrate a strong general analogical component in children's cognitive development.

9.4. Conclusions

The present research provides strong empirical support for the claim that analogies are particularly useful to the development of young children's knowledge within both reading and addition. In particular, the findings illustrate how the use of more detailed research methodologies, including measures of individual strategy choice and appropriate analytic techniques (cluster analysis), can provide a more detailed characterisation regarding children's use of analogical reasoning in the context of reading and addition.

In the reading domain, using retrospective verbal self-reports allows a more accurate and precise assessment of children's analogical performance in reading. Furthermore, children's patterns of performance on solving series of conceptually related problems in reading allows for the identification of different profiles of analogy. Children appear to differ in the extent to which they can make analogies based on shared orthographic relations and shared phonological relations. Both seem to provide an important framework for characterising reading analogy and thus indicate possible alternative pathways to reading development. Furthermore, the profiles of analogical reasoning are strongly related to children's phonological knowledge but not necessarily related to other traditional forms of analogical reasoning skills.

The findings also illustrate how analogy is important for children's addition knowledge. Specifically, children frequently use their knowledge of conceptual relations (commutativity and additive composition) to solve conceptually related addition problems. Children appear to develop an earlier ability to make analogies based on their knowledge of commutativity than additive composition and furthermore, analogical performance is systematically associated with children's domain-specific problem solving skills rather than their traditional analogical reasoning skills. The analogical reasoning tasks included in the thesis provides a new methodological framework for the study of analogical reasoning in children's mathematics and offers a promising approach to developing current cognitive models of mathematical development.

There were also strong links between analogical reasoning skills in the context of reading and addition. The present findings suggest strong patterns of similarity in children's use of analogies in reading and addition together and this presents a new promising approach to the study of children's cognition. In conclusion, the present findings show significant promise in developing our current understanding of analogical reasoning and in devising new and exciting methodologies for the study of analogical reasoning in future research. Moreover, it is likely that exploring the nature and development of analogical reasoning skills across specific educational contexts, including reading, addition and beyond is likely to enrich our current understanding of children's development and contribute towards refining research methodologies and developmental theories of children's cognition.

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APPENDIX A.

REAL WORD PROBLEMS USED IN THE READING
ANALOGY TASK IN STUDY 1

Clue word	Target words		
	Orthographic rime	Phonological rhyme	Unrelated controls
List A real word items			
Seed	Weed (24)	Lead (14)	Boat (0)
Cart	Dart (13)	Heart (14)	Herd (1)
Soak	Oak (15)	Joke (15)	Lost (3)
Bait	Wait (18)	Gate (16)	Food (1)
Head	Dead (18)	Said (20)	Swim (3)
Loon	Boon (14)	Tune (17)	Rage (0)
Moat	Coat (21)	Note (20)	Bank (1)
Pear	Tear (11)	Care (12)	Jump (3)
Pour	Four (19)	Door (16)	Desk (2)
Turn	Burn (24)	Stern (3)	Kiss (2)
Fear	Gear (14)	Here (16)	Shop (2)
List B real word items			
Moon	Noon (23)	Rune (19)	Clap (6)
Pain	Main (20)	Lane (22)	Boil (0)
Seen	Keen (23)	Lean (21)	Card (2)
Bold	Told (19)	Mould (17)	Dirt (2)
Tile	Mile (22)	Dial (15)	Dove (0)
Most	Post (25)	Toast (20)	Swan (3)
Corn	Torn (20)	Lawn (20)	Pink (4)
Site	Kite (18)	Light (20)	Tree (1)
Herd	Nerd (19)	Word (20)	Star (1)
Coil	Soil (20)	Doyle (19)	Barn (0)

APPENDIX B.

NON-WORD PROBLEMS USED IN THE READING
ANALOGY TASK IN STUDY 1

Clue word	Target words		
	Orthographic	Phonological	Unrelated
	rime	rhyme	controls
List A non-word items			
Sait	Nait (18)	Tayt (14)	Woot (3)
Fean	Hean (16)	Peen (15)	Jorm (1)
Zorn	Gorn (16)	Jawn (14)	Felp (5)
Rone	Jone (17)	Poan (14)	Cabe (1)
Woon	Poon (16)	Hune (15)	Balk (0)
Solg	Folg (18)	Poulg (14)	Piak (1)
Dite	Yite (14)	Pight (9)	Kusp (4)
Gurp	Turp (18)	Ferp (15)	Onok (0)
Mout	Sout (16)	Towt (14)	Jisp (0)
Jild	Dild (21)	Syld (8)	Yite (1)
List B non-word items			
Nade	Gade (20)	Kaid (18)	Klim (0)
Boup	Toup (17)	Kupe (11)	Poct (0)
Dode	Fode (12)	Noad (14)	Fomp (5)
Kiye	Niye (19)	Figh (12)	Timp (1)
Beme	Feme (15)	Keam (13)	Molp (2)
Keyl	Leyl (17)	Yail (18)	Wesk (1)
Gort	Jort (15)	Lawt (16)	Tesp (5)
Kurp	Nurp (16)	Herp (18)	Tink (5)
Tolt	Nolt (20)	Doult (13)	Shim (3)
Noil	Doil (16)	Poyle (13)	Keeb (1)
Goot	Koot (19)	Luwt (14)	Faif (0)
Nade	Gade (20)	Kaid (18)	Klim (0)

APPENDIX C.

NON-WORD PROBLEMS USED IN THE READING ANALOGY TASK IN STUDY 2

Clue Words	Orthographic		Phonological		Orthographic		Phonological		Unrelated	
	rime		rhyme		beginning		beginning		controls	
List A non-word items										
Sait	Nait (31)		Tayt (29)		Saig (18)		Sayb (14)		Nulk (9)	
Fean	Hean (29)		Peen (33)		Feap (20)		Feek (22)		Sood (6)	
Zorn	Gorn 32)		Jawn (24)		Zort (34)		Zawf (19)		Felp (7)	
Jild	Dild (28)		Syld (22)		Jilm (29)		Jylk (18)		Boct (9)	
Woon	Poon 38)		Hune (26)		Woot (19)		Wupe (8)		Kasp (9)	
Solg	Folg (39)		Poulg (29)		Solp (32)		Soulm (18)		Jorm (17)	
Gurp	Turp (38)		Ferp (34)		Gurm (28)		Gert (26)		Cabe (1)	
Mout	Sout (31)		Towt (29)		Maug (25)		Mowk (20)		Jisp (8)	

APPENDIX C.

NON-WORD PROBLEMS USED IN THE READING ANALOGY TASK IN STUDY 2 (CONTINUED)

Clue words	Orthographic		Phonological		Orthographic		Phonological		Unrelated	
	rime		rhyme		beginning		beginning		controls	
List B non-word items										
Kiym	Niym (29)		Fighm (24)		Kiyd (20)		Kighn (13)		Molp (6)	
Noad	Hoad (29)		Dode (26)		Noak (22)		Nowf (29)		Gamp (6)	
Keyl	Leyl (34)		Yail (29)		Keyn (22)		Kaif (18)		Wask (3)	
Gort	Jort (33)		Lawt (37)		Gorf (32)		Gawb (15)		Tesp (5)	
Kurp	Nurp (39)		Herp (43)		Kurn (31)		Kerf (32)		Helt (6)	
Tolt	Nolt (36)		Doult (30)		Tolp (34)		Towlk (20)		Shim (13)	
Noil	Doil (36)		Poyle (29)		Noim (15)		Noyk (16)		Keeb (9)	
Goot	Doot (27)		Luwat (31)		Goop (33)		Gouk (20)		Faif (5)	

APPENDIX D.

ADDITION PROBLEMS USED IN THE ADDITION ANALOGY

TASK IN STUDY 3

Clue	Target problems			
	Commutativity	Composition	Commutativity	Composition
	analogy	analogy	controls	controls
4 + 9	9 + 4	4 + 3 + 6	6 + 9	8 + 5 + 2
7 + 9	9 + 7	7 + 4 + 5	7 + 6	6 + 8 + 3
2 + 8	8 + 2	2 + 5 + 3	2 + 9	5 + 3 + 4
5 + 4	4 + 5	2 + 3 + 4	6 + 4	2 + 6 + 3
7 + 6	6 + 7	3 + 4 + 6	4 + 8	7 + 5 + 2
6 + 8	8 + 6	4 + 2 + 8	9 + 4	6 + 4 + 5
3 + 8	8 + 3	3 + 6 + 2	2 + 6	3 + 7 + 2
6 + 3	3 + 6	2 + 4 + 3	4 + 8	6 + 2 + 4
6 + 2 + 5	2 + 6 + 5	6 + 7	7 + 4 + 3	6 + 8
2 + 5 + 8	5 + 8 + 2	7 + 8	3 + 7 + 4	9 + 8
5 + 3 + 6	3 + 6 + 5	5 + 9	7 + 2 + 4	5 + 8
6 + 3 + 7	3 + 6 + 7	9 + 7	8 + 4 + 2	6 + 9
3 + 4 + 2	2 + 3 + 4	7 + 2	4 + 5 + 3	5 + 6
6 + 3 + 2	3 + 6 + 2	6 + 5	4 + 3 + 2	4 + 5
3 + 2 + 5	5 + 3 + 2	3 + 7	3 + 2 + 6	7 + 4
3 + 4 + 5	4 + 3 + 5	7 + 5	2 + 4 + 5	8 + 2

APPENDIX E.

NON-WORD PROBLEMS USED IN THE READING

ANALOGY TASK IN STUDY 4

Clue word	Target words		
	Orthographic rime analogy	Partial similarity	Unrelated controls
List A non-word items			
Sait	Nait (30)	Tayt (26)	Nulk (7)
Fea	Hean (33)	Peen (42)	Sood (13)
Zorn	Gorn (35)	Jawn (29)	Felp (4)
Jild	Dild (29)	Syld (27)	Boct (5)
Woon	Poon (49)	Hune (33)	Kasp (7)
Solg	Folg (43)	Poulg (29)	Jorm (18)
Gurp	Turp (46)	Ferp (34)	Cabe (0)
Mout	Sout (38)	Towt (34)	Jisp (2)
List B non-word items			
Kiym	Niym (41)	Fighm (27)	Molp (5)
Noad	Hoad (38)	Dode (21)	Gamp (6)
Keyl	Leyl (32)	Yail (30)	Wask (4)
Gort	Jort (36)	Lawt (34)	Tesp (7)
Kurp	Nurp (48)	Herp (45)	Helt (4)
Tolt	Nolt (46)	Doult (33)	Shim (14)
Noil	Doil (42)	Poyle (32)	Keeb (15)
Goot	Doot (41)	Kuwt (30)	Faif (2)

APPENDIX F.

ADDITION PROBLEMS USED IN THE ADDITION ANALOGY
TASK IN STUDY 4

Clue	Target problems		
	Commutativity analogy	Partial similarity	Unrelated controls
List A problems			
4 + 9	9 + 4	9 + 6	7 + 5
7 + 9	9 + 7	7 + 6	6 + 8
2 + 8	8 + 2	2 + 7	3 + 9
5 + 4	4 + 5	7 + 4	2 + 6
7 + 6	6 + 7	6 + 5	5 + 9
6 + 8	8 + 6	9 + 6	9 + 4
3 + 5	5 + 3	3 + 8	2 + 7
6 + 3	3 + 6	3 + 4	4 + 8
List B problems			
6 + 9	9 + 6	6 + 8	5 + 8
5 + 6	6 + 5	5 + 4	7 + 8
2 + 7	7 + 2	7 + 4	8 + 3
3 + 4	4 + 3	4 + 6	9 + 7
6 + 2	2 + 6	2 + 8	5 + 2
3 + 7	7 + 3	3 + 5	5 + 7
7 + 8	8 + 7	6 + 7	9 + 4
9 + 8	8 + 9	9 + 5	7 + 6

APPENDIX G.

EXAMPLES OF THE TRADITIONAL REASONING TASKS USED IN STUDIES 2 AND 3

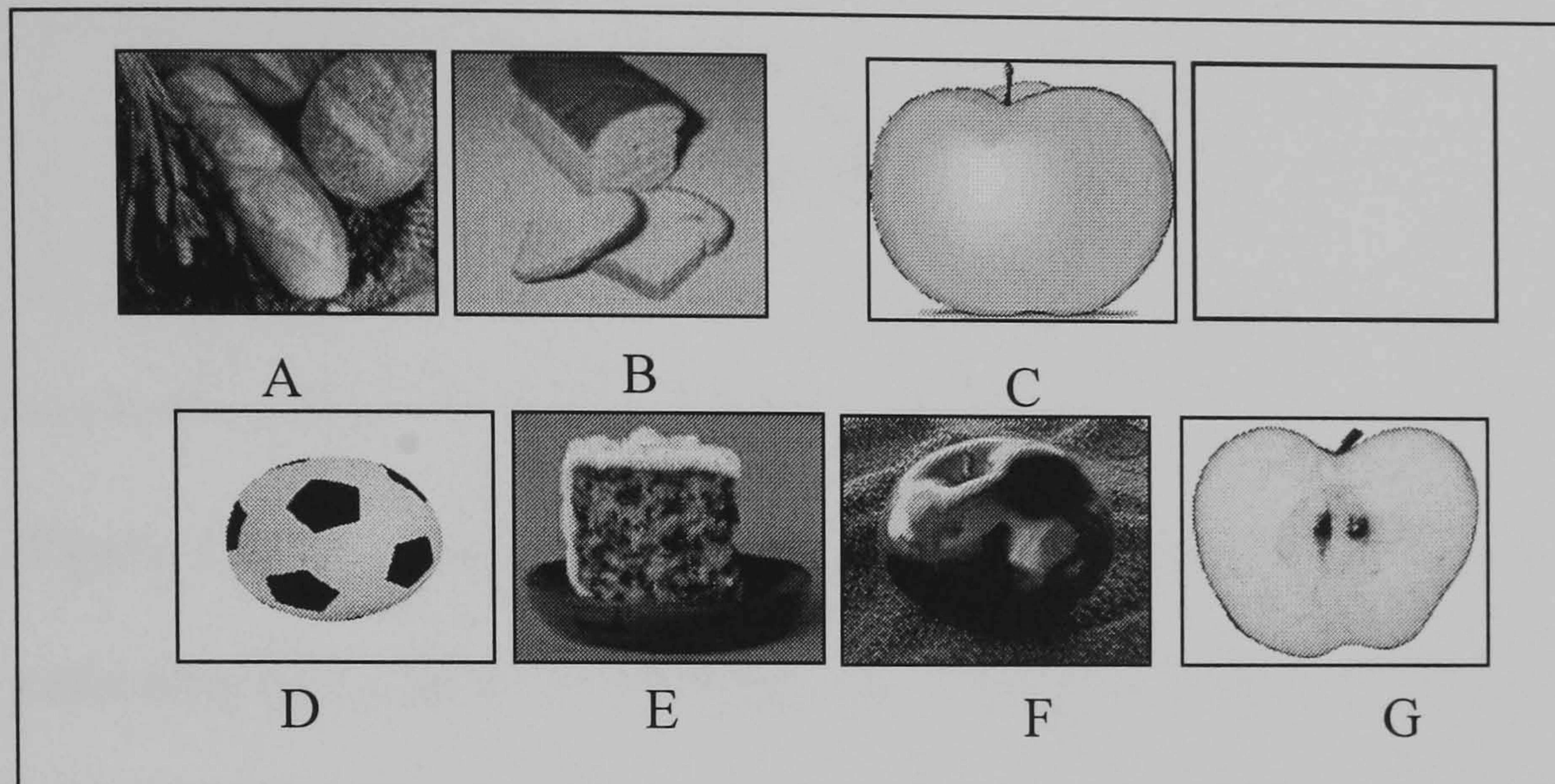


Figure 1: Stimuli used in the analogy based on the relation *cutting* in the causal reasoning task (*bread is to slice of bread as apple is to slice of apple*).

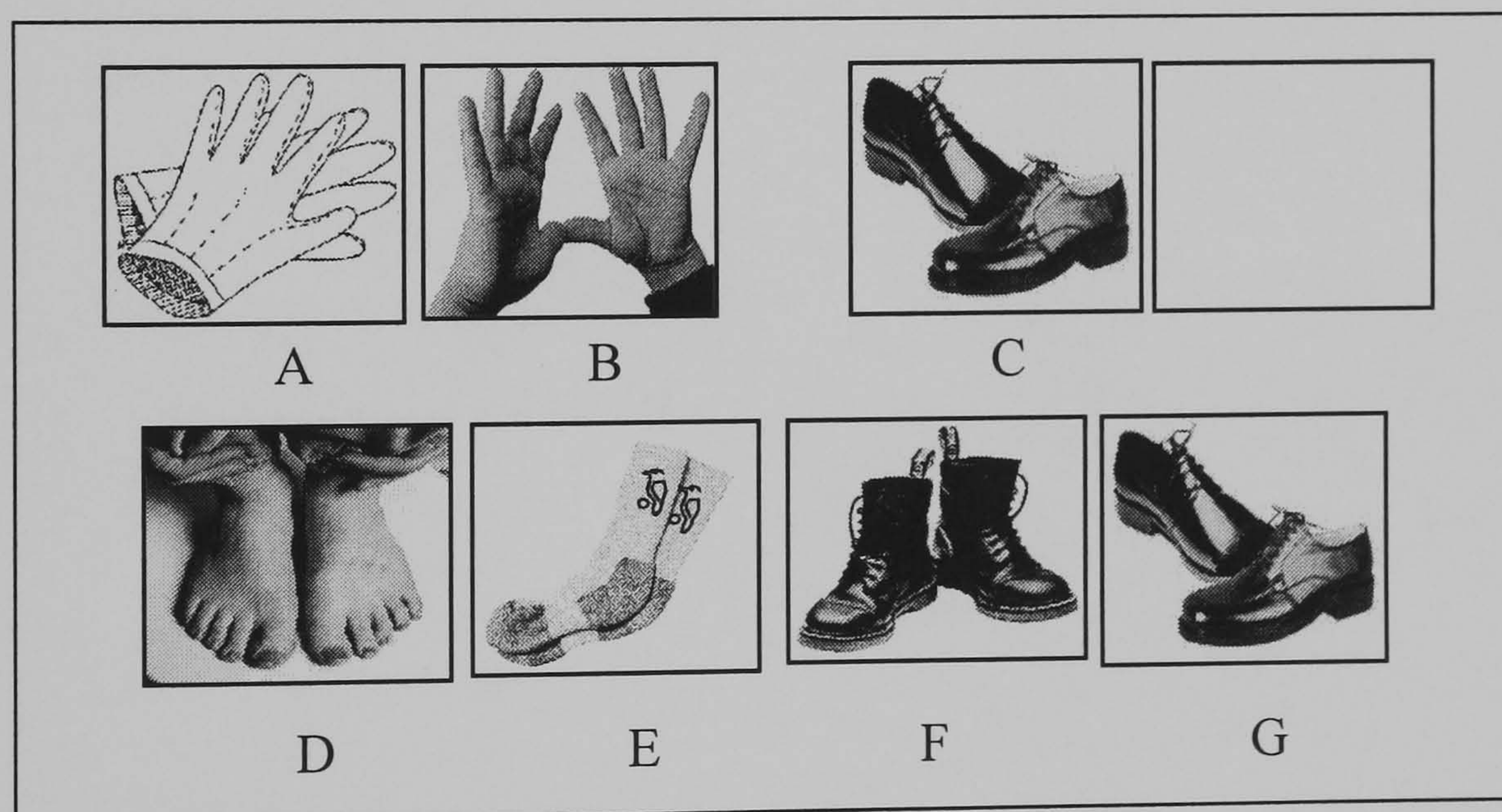
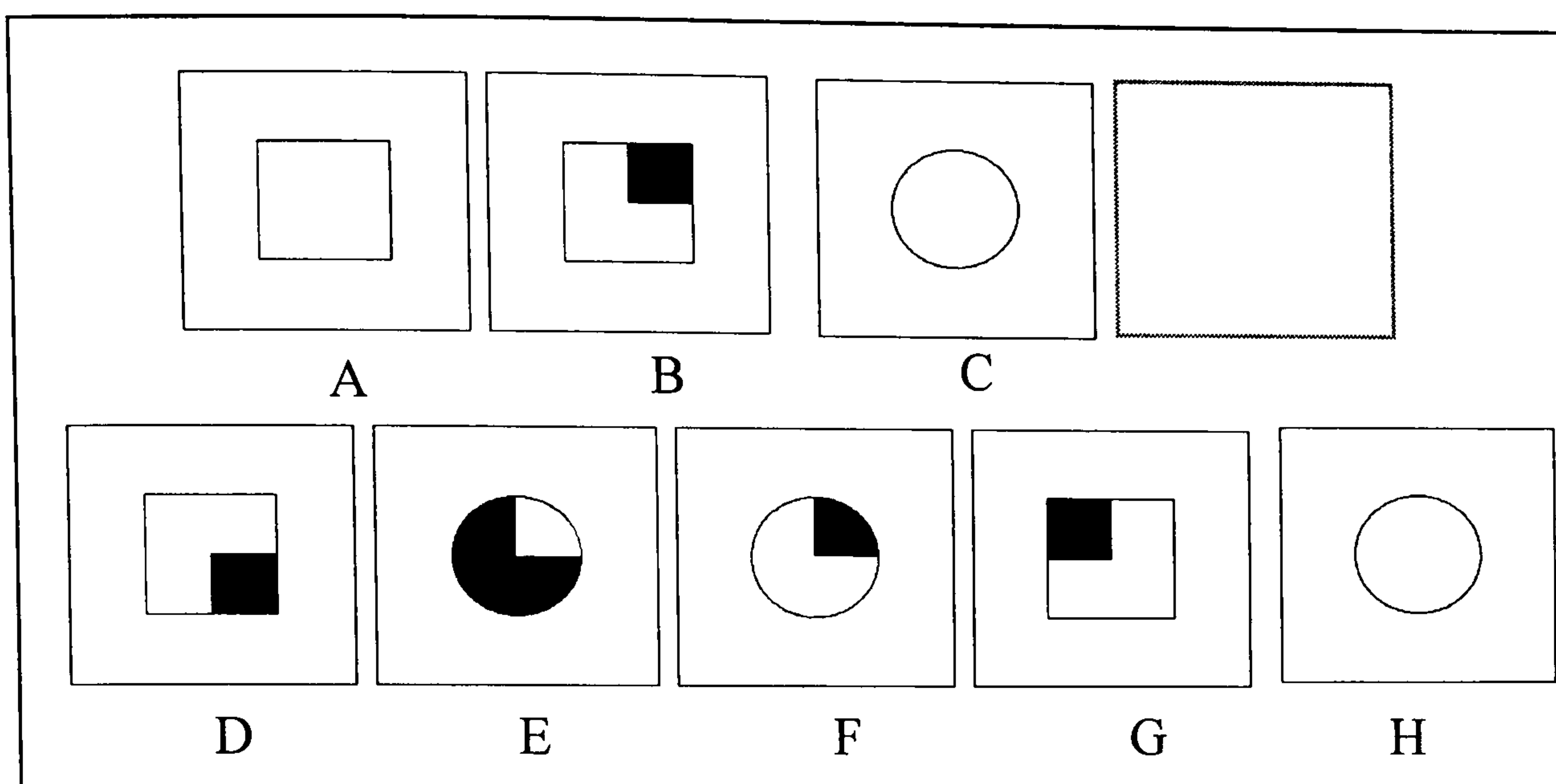


Figure 2: Stimuli used in the analogy based on the relation *wear* in the thematic reasoning task (*gloves are to hands as shoes are to feet*).



*Figure 3: Stimuli used in the analogy based on *proportions* in the visual reasoning task (square: $\frac{1}{4}$ square shaded:: circle: $\frac{1}{4}$ circle shaded).*